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(Vol. XXVIII.—February, 1893.)

RESTORATION OF THE CABLE ENDS OF THE COVINGTON AND CINCINNATI SUSPENSION BRIDGE.*

By G. BOUSCAREN, M. Am. Soc. C. E.

READ MARCH 1ST, 1893.

The Covington and Cincinnati Suspension Bridge was designed and built by John Roebling. Begun in 1856, the work of construction was interrupted by the vicissitudes of the War of the Rebellion, and the bridge was only completed and opened to travel January 1st, 1867. It was the first bridge built over the Ohio River below Wheeling, and had the longest span of any bridge in existence until it yielded the supremacy to the New York and Brooklyn Bridge, built in 1870–83 by the same engineer.

* Discussions on this paper received before May 1st, 1893, will be published in a subsequent number.

The principal dimensions of the bridge are as follows :

	Feet.
Middle span from center to center of towers	1 057
Side spans from center of towers to face of anchor walls	281
Elevation of floor above low water at center of middle span at ordinary temperature	103
Elevation of floor at towers above low water	91
Elevation of saddles on towers above low water	197
Width of wagon-way in the clear	20
Width of sidewalks, each	7

The cable system is composed of two main cables $12\frac{1}{3}$ ins. diameter, cradled from 50 ft. apart over the towers to 25 ft. at the center of the middle span, and 36 ft. at the anchorages ; re-enforced by 76 inclined stays $2\frac{1}{2}$ ins. in diameter. The stiffening trusses are of iron 10 ft. high. A full description of the bridge and of the methods applied in its construction are found in Roebling's report of 1867, addressed to the directors and stockholders of the bridge company.

Roebling's faith in the preservative quality of cement mortar led him to bury the anchor chains and cable ends of this bridge in masonry, as he had done before at Niagara and for the Suspension Aqueduct over the Allegheny River at Pittsburgh. His assurance in this respect was so positive, and the confidence which it inspired in the directors of the bridge company was so great, that they demurred to having an examination made of the buried parts of the cables for a long time after a similar examination had revealed serious deterioration in the cable ends of the Niagara Bridge.

In the summer of 1891 it was finally decided to have such examination made under the direction of the writer, and to confine the work for that season to the southeast anchorage only. The anchor wall above the level of the bridge floor is shown in Figs. 1 and 2 (Plate X). The masonry is of sandstone from the Buena Vista quarries on the Ohio River, near Portsmouth. It is ashlar-faced, with rubble filling, laid with Louisville cement mixed with lime, and is capped with large stone slabs jointed with pitch.

Each main cable is composed of seven strands, and each strand is made of 740 iron wires of No. 9 Birmingham gauge ; 18 ft. of this wire weigh 1 lb., which corresponds to $\frac{1}{60}$ of a square inch in sectional area. The wire was manufactured by Richard Johnson and Nephew,

at Manchester, England. The ultimate tensile strength of one wire is given by Roebling in his report at 1 620 lbs., which would make the ultimate strength of one cable

$$740 \times 7 \times 1\,620 = 8\,391\,600 \text{ lbs.} = 4\,195.8 \text{ tons.}$$

Every strand is wrapped at intervals with small wires, and the seven strands composing one cable are wrapped continuously with No. 10 wire, forming a cylinder $12\frac{1}{3}$ ins. in diameter.

The wrapping of the main cable ends about 1 ft. inside of the anchor wall, where the seven strands begin to diverge, to connect with the anchor chain on two pins $4\frac{1}{2}$ inches in diameter, about 16 ft. back from the face of the wall, as shown in Figs. 3 and 4 (Plate XI). Each strand divides in four equal parts looped on cast shoes, these shoes and the chain bars alternating on the pins. In this manner seven bars and three strands connect together on the upper pin, and ten bars and four strands connect together on the lower pin.

The first link of the anchor chain composed, as stated above, of 17 eye-bars of iron, has an aggregate section of 190 sq. ins., and is intended to be equal in strength to the cable.

The chain of small eye-bars shown in Figs. 3 and 4 (Plate XI) above the cable connection served as an anchorage for the temporary foot-bridge during the construction of the bridge and is now used to secure the end of the hand-rope above the main cable.

The masonry was taken down as indicated by the hachure lines in Figs. 1 and 2 (Plate X), sufficiently to uncover the entire length of the strands and about 4 ft. of the anchor bars which connect with them.

The character of the masonry was poor, the vertical joints and beds between the dimension stones of the casing were very irregular in thickness and imperfectly filled with mortar; numerous cavities were found in the rubble filling, which in the case of the northwest wall were of sufficient size to admit freely the full length of a man's arm. The mortar was very irregular in quality and showed great variation in the proportion of sand and lime used with the cement; as a rule, it was defective in hardness and saturated with moisture, especially in the immediate neighborhood of the cable strands which had been bedded and grouted in the rubble. Quite a number of wooden chips and wedges were found imbedded in the mortar and reduced to the consistency of a soft pulp by the united action of air and water; in the case of the northwest abutment, a piece of yellow pine scantling over 4 ft. long was found in the mortar between the strands.

The mortar in immediate contact with the wires was impregnated with iron rust and formed a very hard crust around the strands, which could only be removed with great difficulty and care, without damage to the wires. The outside wires of the strands were, as a rule, bonded together in a matrix of rust, giving to the strands the appearance of solid bars, yet in a few spots the wires were bright and well preserved.

The cleaning of the wires was a tedious operation. Steel scrapers and brushes were used for this purpose with an abundant application of coal oil; the use of chisels and points was forbidden, to avoid further injury to the wires. After the outside crust and the wire wrappings had been removed, wooden wedges were used to open the strands and insure a thorough penetration of the oil; but where the strands were looped on the cast shoes, and where they came together to form the body of the cable, the cleaning and oiling were necessarily very imperfect.

The outside wires of every strand, when cleaned, showed a considerable reduction in sectional area; many of them parted during the process of cleaning, being entirely eaten through by rust. This was generally the case where a piece of wood or stone was in contact with them. The inside wires were in comparatively good condition.

After a careful examination of the cleaned wires, the loss of strength of the cable was estimated to be about $\frac{1}{8}$ by reason of reduced area.

To ascertain what, if any, deterioration had taken place in the quality of the iron itself, 12 pieces were cut out from the broken wires where they were in the best condition, and tested for tensile strength in a Riehlé machine. The results were as follows:

No. of Specimen.	Ult. Strength.	Elongation in 8 ins.	Remarks.
1	1 525	$\frac{1}{32}$ in.	
2	1 490	$\frac{1}{32}$ "	
3	1 420	$\frac{1}{32}$ "	
4	1 670	0 "	Broke in clamp.
5	1 600	$\frac{1}{16}$ "	
6	1 650	$\frac{1}{32}$ "	
7	1 590	$\frac{1}{32}$ " scant.	
8	1 580	$\frac{1}{32}$ " scant.	
9	1 600	$\frac{1}{32}$ "	
10	1 620	$\frac{1}{16}$ "	Broke near clamp
11	1 710	0 "	Broke in clamp.
12	1 570	$\frac{1}{16}$ "	
Average.......	1 585		

Showing an average loss in strength of about 2% which may be due to a slight decrease of section. As the original ductility of the wire is

not known, no conclusion can be drawn from the elongations of the broken specimens.

The chain bars were pitted with rust in spots, but were not seriously injured. The circumstances dictated two things to be done:

First.—The restoration of the cable end to its original strength.

Second.—A permanent protection of the same against further damage by rusting.

The first object was accomplished by the means of four auxiliary iron bars, 1 x 3 ins. in section, looped on the ends of the two pins, connecting the cable with the anchor chain, and made taut by screwing at their threaded ends against a head block bearing against a system of friction collars clamped on the cable outside of the walls, as shown in Figs. 3, 4 and 5 (Plate XI).

Fortunately, the connecting pins projected beyond the anchor bars, leaving an available space at the ends of $1\frac{1}{2}$ to $2\frac{3}{8}$ ins. for a bearing for the auxiliary bars, as shown in Fig. 6 (Plate XI).

The friction hold on the cable outside of the wall was secured by 30 collars, 4 x $\frac{3}{4}$ ins., clamped on with two bolts $1\frac{1}{2}$ ins. diameter, these collars being truly dressed on the face, fitted closely against each other, forming a continuous sleeve 10 ft. long over the cable. Four angle irons, 5 x 5 ins., with bars $1\frac{1}{2}$ x 5 ins. between them, are riveted to the last 10 collars, to give the necessary bearing for the head-block. The head-block is made of six steel plates, 2 x 13 x 26 ins., dressed on all faces and assembled together, breaking joints, by means of 20 turned bolts, $1\frac{1}{4}$ ins. diameter, with countersunk heads. The details of the auxiliary bars, clamps and block are shown in Figs. 7, 8, 9, 10, 11 and 12 (Plate XI).

Before placing the clamps in position the old paint was burnt and scraped off the cable, and a fresh, thick coat of white lead applied and sprinkled heavily with lake sand to give a better grip. The clamp bolts were then screwed up by two men acting at the end of a 30-in. wrench.

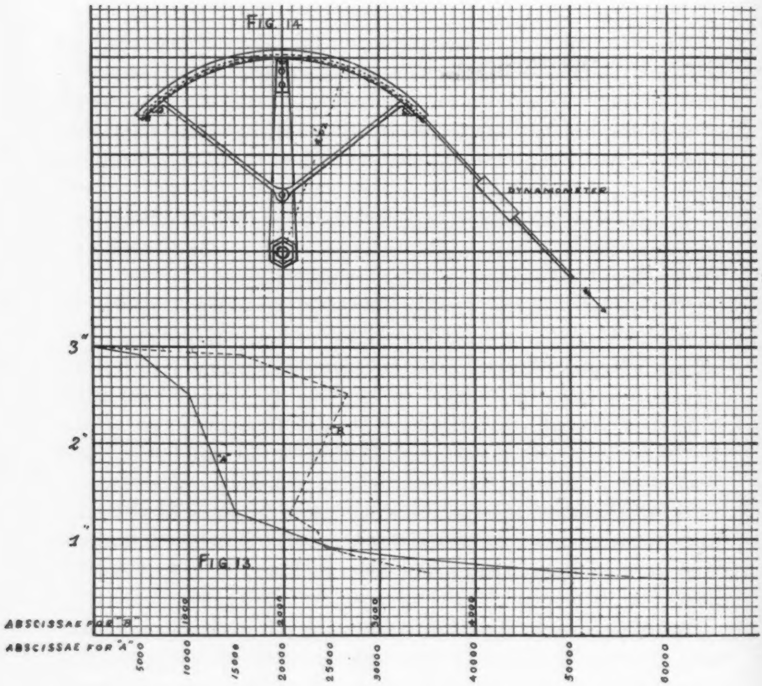
The estimated tensile stress in a clamp bolt was...... 18 000 lbs.

Aggregate pressure on the diameter of the cable from 60 bolts $= 60 \times 18\,000$........................ $= 540$ tons.

The frictional resistance from the same on $\frac{18}{19}$ of the circumference of the cable, supposing a uniform rate of pressure normal to circumference $\frac{18}{19} \times 0.25 \times 540 \times \pi$.. $= 401.4$ "

Estimated loss of strength of cable $\frac{1}{8} \times 4\,200$ tons... $= 525$ tons.
Re-enforcement from auxiliary bars $3 \times 8 \times 25$ tons.. $= 600$ "
Working stress of bars $\frac{1}{5} \times 600$ .... $= 120$ "
Margin of safety of frictional resistance over tension

$$\text{in bars} = \frac{401.4}{120} = 3.34.$$



The adjustment of the auxiliary bars to a working stress of 10 000 lbs. per square inch was made in the following manner: Six cylinders were cast out of the same pig of lead and turned to the exact dimensions of diameter = 2 ins., length = 3 ins. Two of these cylinders were pressed successively in a Riehlé testing machine in a direction parallel to their axes. The pressure was applied by increments of 5 000 to 30 000 lbs., then by increments of 10 000 to 50 000 lbs., this being the limit of capacity of the testing machine. The heights of the

cylinders were carefully measured after each application of pressure, which lasted 10 minutes, to give the necessary time for the compression of the lead to take place. The two operations gave almost identical results, showing uniformity in the quality of the lead.

Curve *a* in Fig. 13 (page 52) shows the relation between the compressions and the total pressures, the ordinates representing the heights of cylinders and the abscissas the corresponding pressures. Curve *b* shows the relation between the compressions and the pressures per square inch, deduced from calculated areas of sections corresponding to the heights of cylinders at the different stage of the tests. The pressure scale for curve *b* is ten times larger than for curve *a*.

These curves show that a critical point exists in the flow of lead under pressure between 2 000 and 2 800 lbs. per square inch, the rate of flow being regular after the critical point is passed. The capacity of the testing machine used being unfortunately limited to 50 000 lbs., the reduced height of cylinder, due to a pressure of 60 000 lbs., could not be measured directly, but was deduced constructively from curve *a* and found to be very approximately 0.60 of an inch.

The four remaining cylinders were placed between the head block and four bearing plates resting on the four flanges of the friction sleeve on the cable, and the nuts of the auxiliary bars being well lubricated, were turned uniformly until the four cylinders had been reduced to the desired height of 0.60 in.

At the last turn the power required to turn each nut was measured by the use of a wrench shown in Fig. 14 (page 52). A small channel iron bent on an arc of a circle with the arm of the wrench for radius was attached thereto, and a spring dynamometer, tied to the pulling rope fitting in this rim, recorded the pulls on the rope at the last turn for each nut. These being noted, the lead cylinders and bearing plates were taken out and the same operation repeated with the head block in place, care being taken to apply for each nut the pull previously recorded for it. The readings of the dynamometer were as follows:

No. of Rod.	Dynamometer Reading.	No. of Rod.	Dynamometer Reading.
1	300	5	287
2	237	6	225
3	225	7	200
4	275	8	200

The subsequent adjustment of the rods for the other anchorages was made without the use of lead cylinders, and with the uniform pull of 250 lbs. on the wrench for each nut.

The first suggestion with regard to a plan for the future preservation of the cable end was to paint it thoroughly and to enclose it in a chamber where it would be protected from the weather and accessible for inspection and repainting from time to time. But it is a well-known fact that unless rusty iron is cleaned thoroughly before painting, it will continue to rust under the paint, which in such case only affords a delusive sense of security. For this reason painting could not be depended upon here, as the rust could only be removed from the surface wires where the strands come together and where they are looped around the cast shoes on the anchor chain pins. At these points the wires could not be loosened at all for the purpose of cleaning and remained imbedded in rust. The safest plan against future deterioration of the iron seemed to be the entire exclusion of air and moisture by a permanent oil bath.

An iron casing was constructed extending from the first friction collar on the cable to a short distance beyond the connecting pins on the anchor chain and enclosing completely the iron-work between these points. Figs. 15, 16, 17 and 18 (Plate XII) show the casing in detail. It is built of ¼-in. plates stiffened with angle irons and riveted in position. All riveted joints were thoroughly calked before painting. The upper end of the tank is closed with a cast-iron head made of four flanged plates with proper openings for the cable and the auxiliary bars, bolted to an angle iron flange on the tank. All joints were made tight by the use of a lead tubing ¼ in. diameter, laid in a small groove on the face of the flanges. The joint between the cable and plates was made by pouring molten lead and caulking.

The lower edge of the bottom of the tank is flanged with an angle iron butting against the dressed face of the large stone which supports the cast-iron shoes and the heads of the anchor bars. This joint was filled with pitch poured through the two hand-holes shown in the sides of the tank near the bottom.

A block of béton built in the shape of an arch, back of the connecting pins so as to clear the heads and necks of the anchor bars, closed the lower end of the tank. The sides and top of the tank overlapped the finished faces of the béton block about 5 ins., leaving a

space of about ½ in. between the iron and the béton which was filled with pitch, using for that purpose the hand-holes shown in the lower top plate of the tank. A 2-in. pipe from the top of the tank, near the cast-iron head, serves for pouring in the oil. A pipe of the same size from the lower part of the bottom allows the oil to be drawn out if desired.

The masonry was rebuilt in rubble under the tank within a few inches of the iron, and the remaining space filled with béton, giving a solid bed of masonry to the tank. The stones forming the original faces of the wall were all relaid in place after dressing to a uniform width of 2 ft., and the space between them and the sides of the tank was filled with béton, but no masonry was built on top of the tank which now forms the floor of a chamber accessible through an iron door. The space between the cable and the square opening left for its passage through the front of the wall was filed with béton. The chamber is closed at the top with iron beams and brick arches, upon which rest the stone slabs of the roof.

In outside shape and appearance the anchor wall is the same as it was before the work was done. Figs. 19 and 20 (Plate XIII) show the construction of the chamber with the tank in position.

In reconstructing the masonry, Portland cement was used exclusively. All the béton was made in the proportion of 2 parts of sand to 1 of cement.

After the work of reconstruction was completed, the tank was filled with paraffine oil, about 1 500 galls. being required. Paraffine oil was preferred to any other on account of its neutral qualities. Unlike vegetable and animal oils and fats, it does not oxidize in contact with the air with development of acid products, it does not get thick and rancid, it will preserve its purity indefinitely and has absolutely no chemical effect on iron. The grade of oil selected is known on the market under the name of "Zone" oil, its flashing point is at 350° Fahr., at 32° it begins to show crystals of solid paraffine, 1 gall. weighs 7½ lbs. and cost the bridge company about 13½ cents. Another advantage of this oil for this special purpose is its great fluidity, which allows it to penetrate thoroughly all interstices between the wires.

This power of penetration was well demonstrated in the case of the southeast anchorage. The level of oil in the tank was carefully

gauged through the vertical supply pipe, and a steady fall was recorded from day to day, which could only be explained by the supposition that the oil was making its way into the masonry, through the béton block at the lower end, there being no apparent leak in the iron casing. This inference was confirmed at the end of several weeks by the appearance of oil through the joints of the masonry on both sides of the wall, some distance back and below the tank. These exudations gradually increased until they had covered a large surface.

The loss in the tank was not great during the winter, but increased materially with the return of warm weather in the spring. It was then decided to draw the oil out and replace it with paraffine wax.

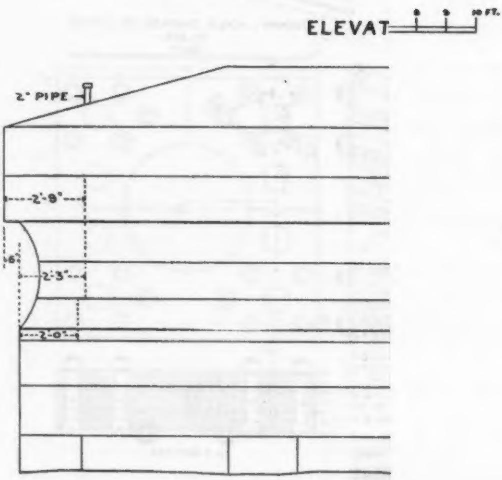
Several grades of wax are found on the market which differ only by the proportion of oil left in the wax. The cheaper grade, or crude wax, which contains the greater proportion of oil was used. It melts at 116° Fahr., and cost the bridge company 6 cents per pound. It was melted in a steam kettle set on top of the wall and connected with the supply pipe of the tank. The boiler of one of the hoisting engines used in rebuilding the masonry supplied the steam.

The three other cable ends of the bridge were restored during the summer and fall of 1892. Being built alike, the same plan was used; the only departure made from the method of procedure described for the southeast anchorage was that the arched face of the béton block inside the tank received a thick coating of pitch, with a view of preventing the leaking out of the oil through that channel. The remedy has been entirely effective to the present time, the oil has not made its appearance on the walls, and the levels of oil in the tanks have not varied perceptibly.

The entire work was executed under the immediate supervision of Mr. C. N. Miller, Jun. Am. Soc. C. E.

PLATE X.
M. SOC. CIV. ENGRS.
, XXVIII, No. 578.
TO CINCINNATI SUSPENSION BRIDGE.

ELEVAT



ELEVATELEVATION–NORTH END.
FIG. 2.

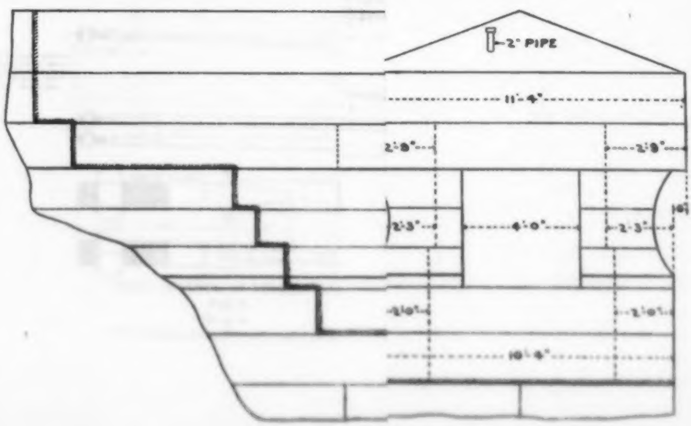


PLATE
TRANS. AM. SOC.
VOL. XXVIII,
BOUSCAREN ON REPAIRS TO CINC

ND CINCINNATI SUSPENSION BRIDGE.
ONS OF SOUTH-EAST ABUTMENT.

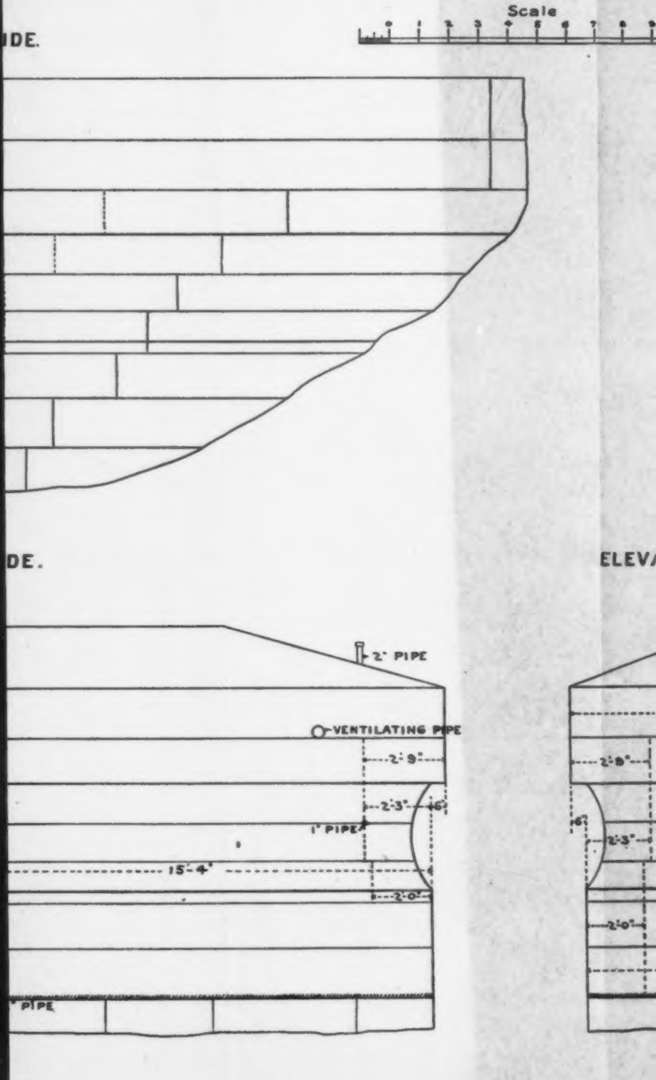
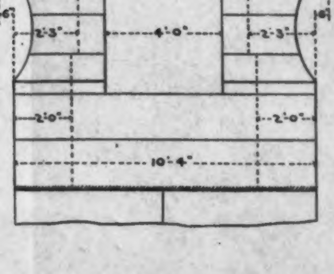


PLATE X.
S. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 578.
RS TO CINCINNATI SUSPENSION BRIDGE.

7 8 9 10 FT.

ELEVATION—NORTH END.
FIG. 2.



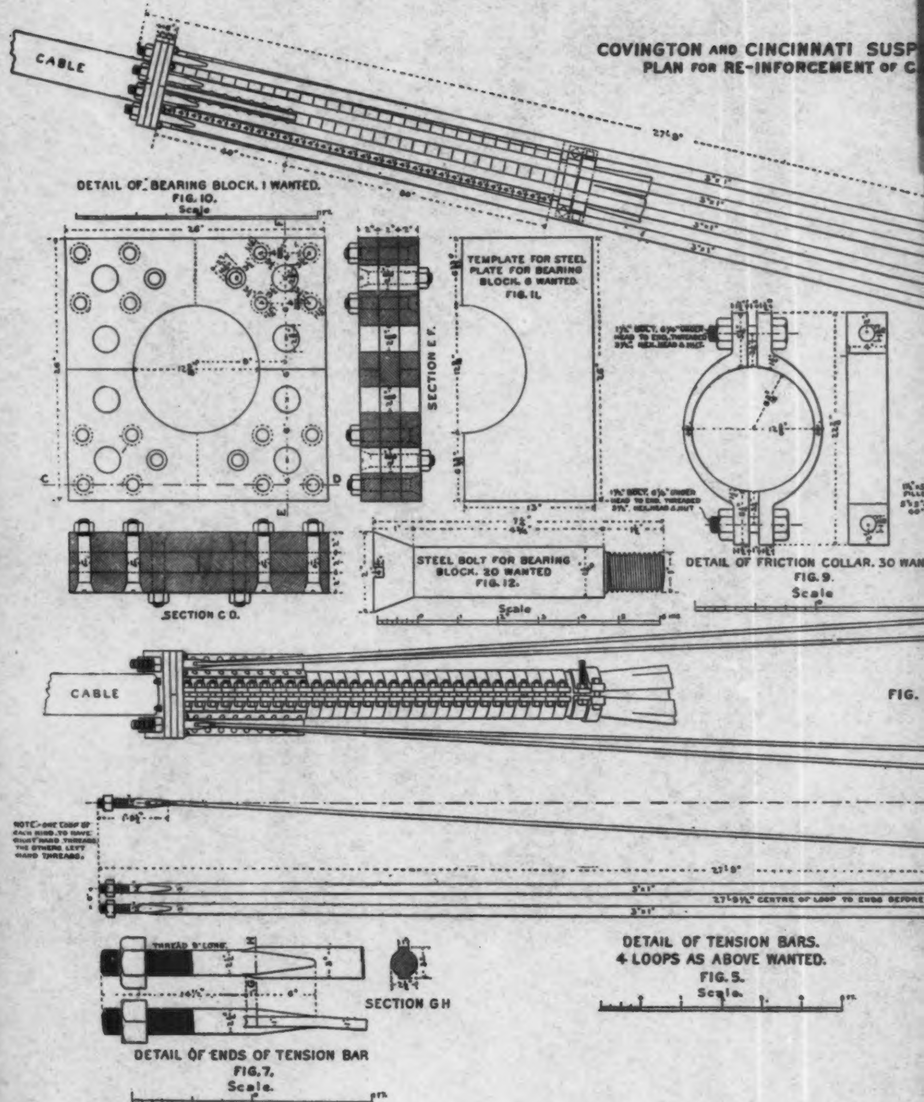
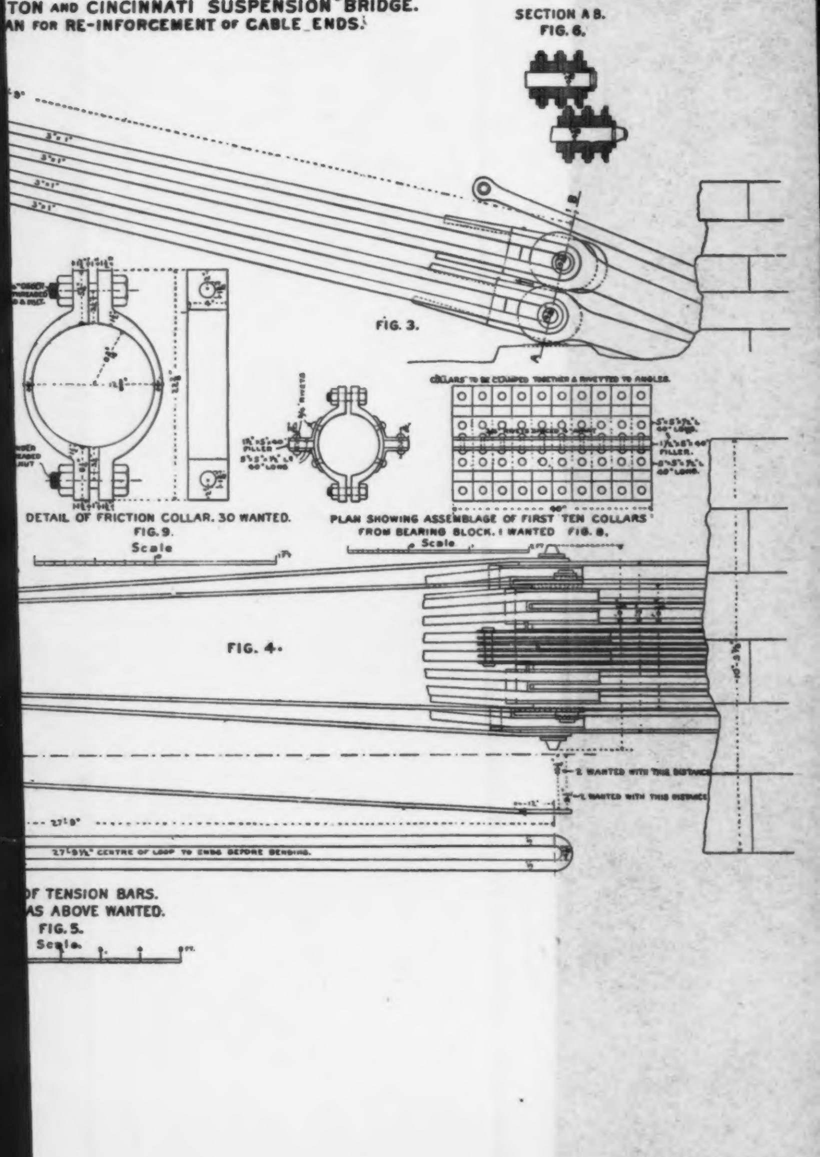

COVINGTON AND CINCINNATI SUSP
PLAN FOR RE-INFORCEMENT OF C
CABLE
DETAIL OF BEARING BLOCK. 1 WANTED.
FIG. 10.
Scale
TEMPLATE FOR STEEL PLATE FOR BEARING BLOCK. 6 WANTED.
FIG. 11.
SECTION E F.
SECTION C D.
STEEL BOLT FOR BEARING BLOCK. 20 WANTED
FIG. 12.
Scale
DETAIL OF FRICTION COLLAR. 30 WAN
FIG. 9.
Scale
CABLE
FIG.
DETAIL OF TENSION BARS.
4 LOOPS AS ABOVE WANTED.
FIG. 5.
Scale.
THREAD 9" LONG.
SECTION G H
DETAIL OF ENDS OF TENSION BAR
FIG. 7.
Scale.

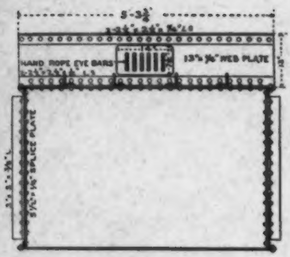
PLATE XI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 578.
BOUSCAREN ON REPAIRS TO CINCINNATI SUSPENSION BRIDGE.

TON AND CINCINNATI SUSPENSION BRIDGE.
AN FOR RE-INFORCEMENT OF CABLE ENDS.

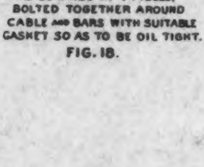


BRIDGE.

COVINGTON
PLAN FOR
CASING TO



SECTION A B.
FIG. 17.



VIEW OF CAST IRON HEAD
TO BE MADE IN 4 PIECES;
BOLTED TOGETHER AROUND
CABLE AND BARS WITH SUITABLE
GASKET SO AS TO BE OIL TIGHT.
FIG. 18.

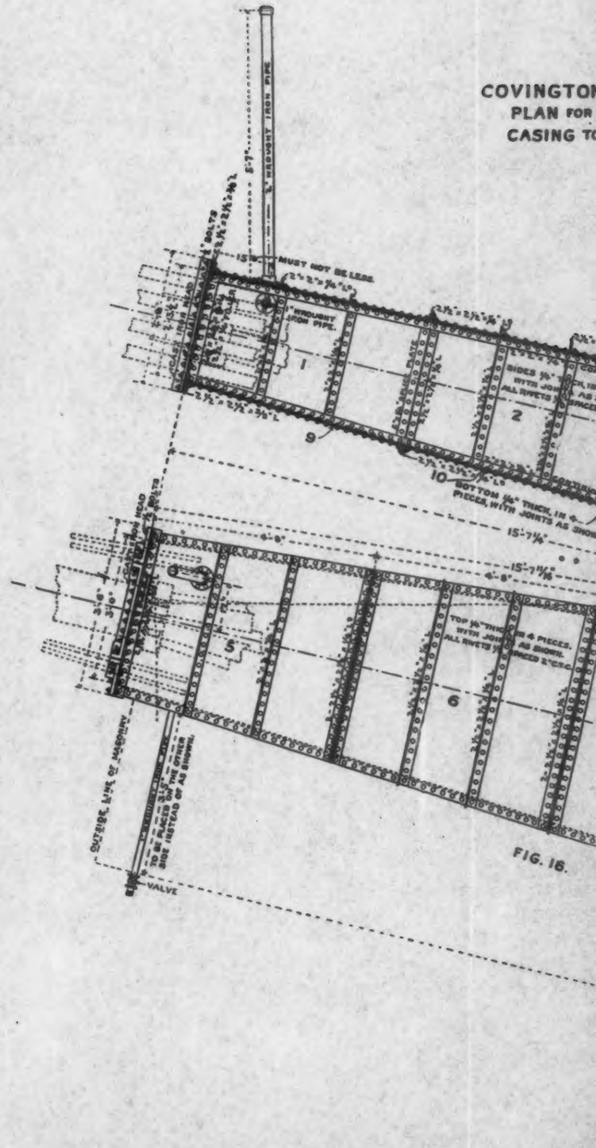


FIG. 16.

P
TRANS. AM.
VOL. X
BOUSCAREN ON REPAIRS TO

COVINGTON AND CINCINNATI SUSPENSION BRIDGE.
PLAN FOR WROUGHT IRON CASING FOR CABLE END.
CASING TO BE OIL-TIGHT AND FILLED WITH PARAFFINE OIL.

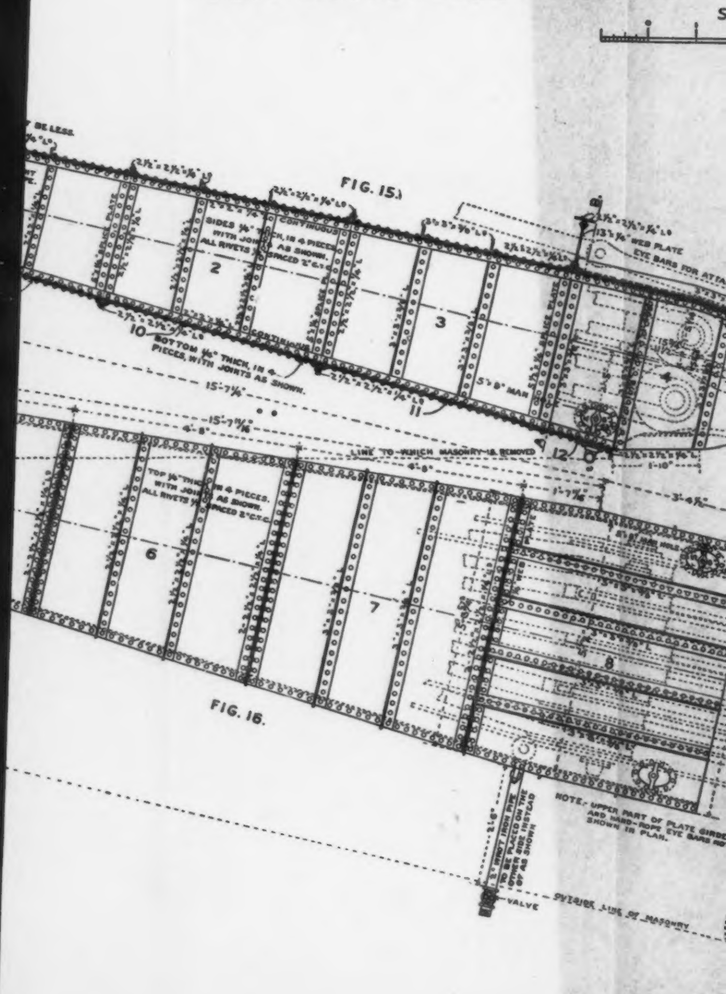
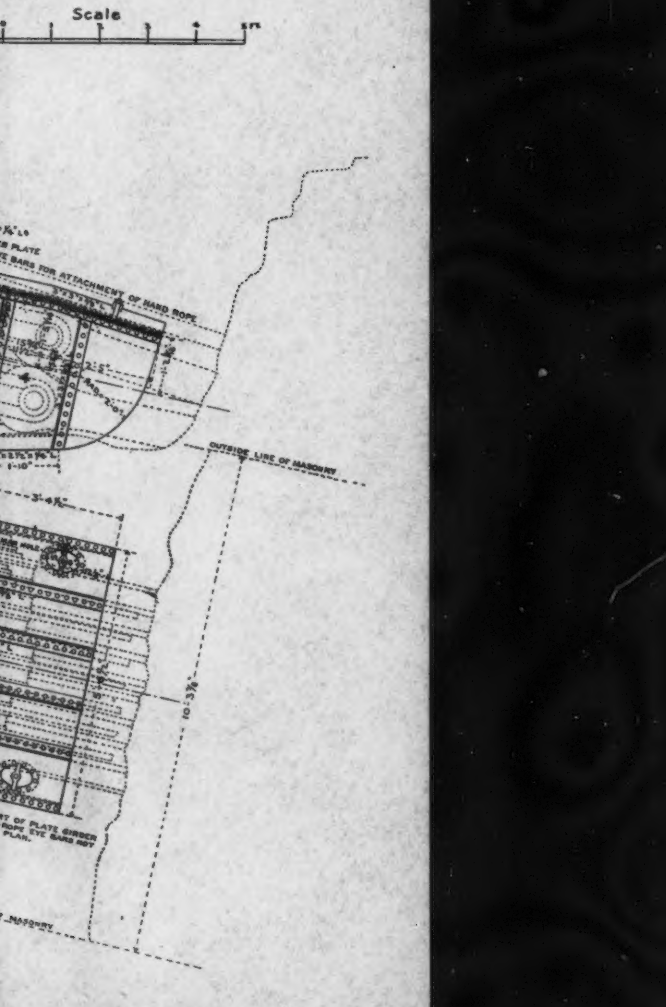
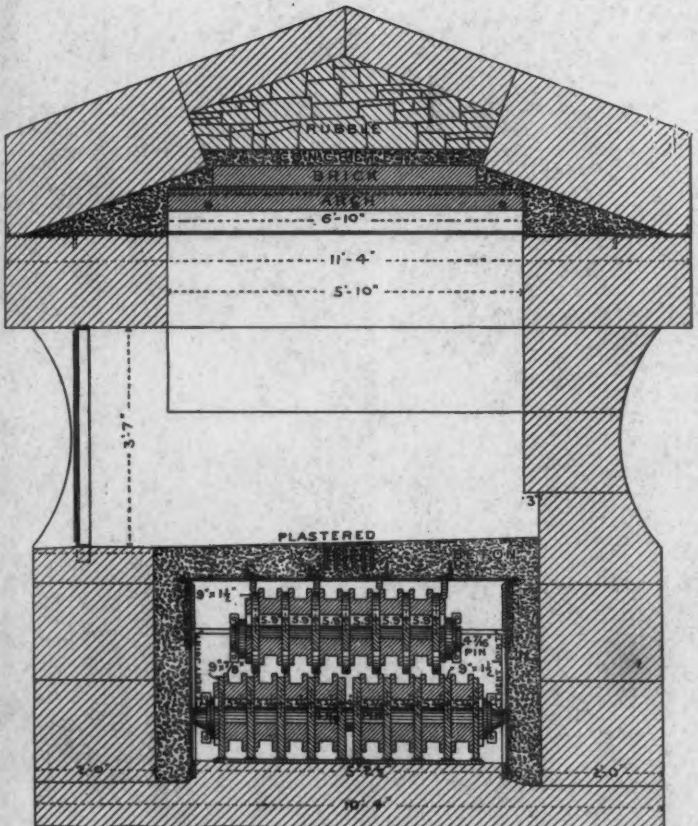


PLATE XII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 578.
REPAIRS TO CINCINNATI SUSPENSION BRIDGE.

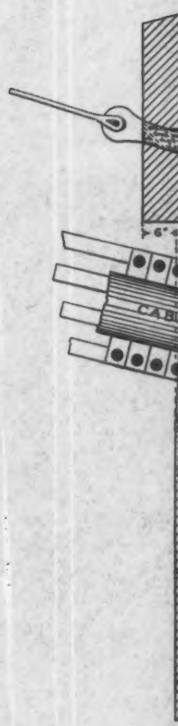
RIDGE.
ND.
OIL.



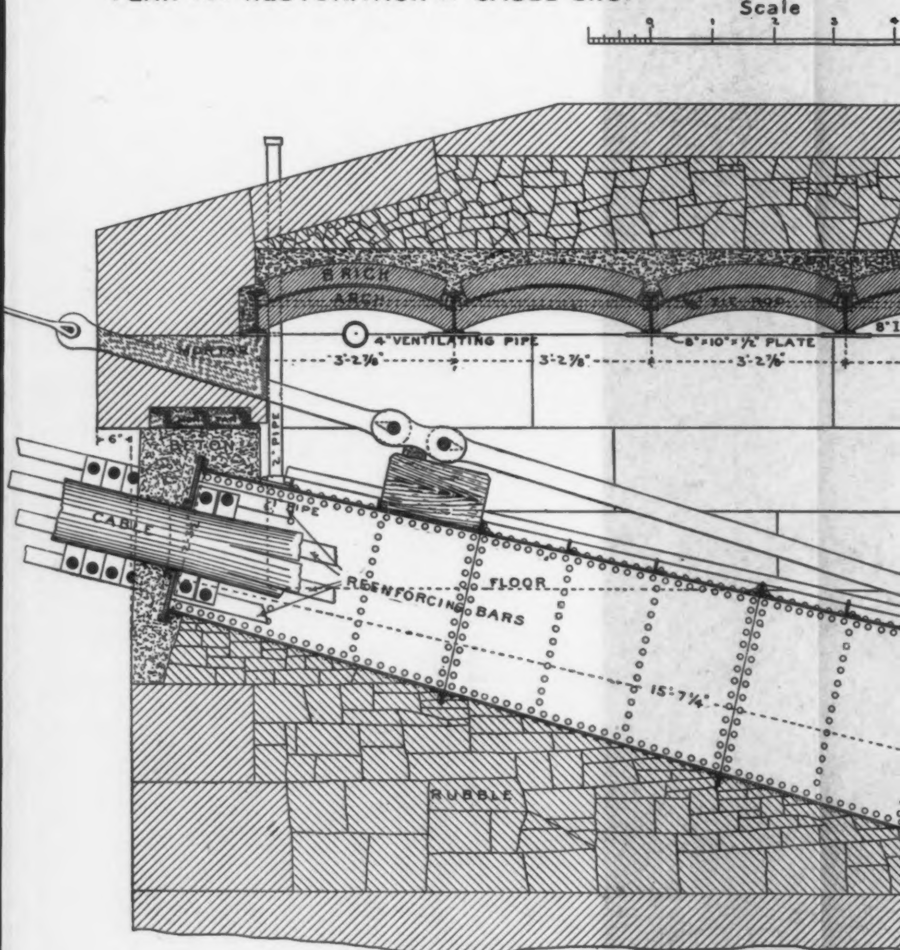


SECTION A B.
FIG. 20.

COVING
PL

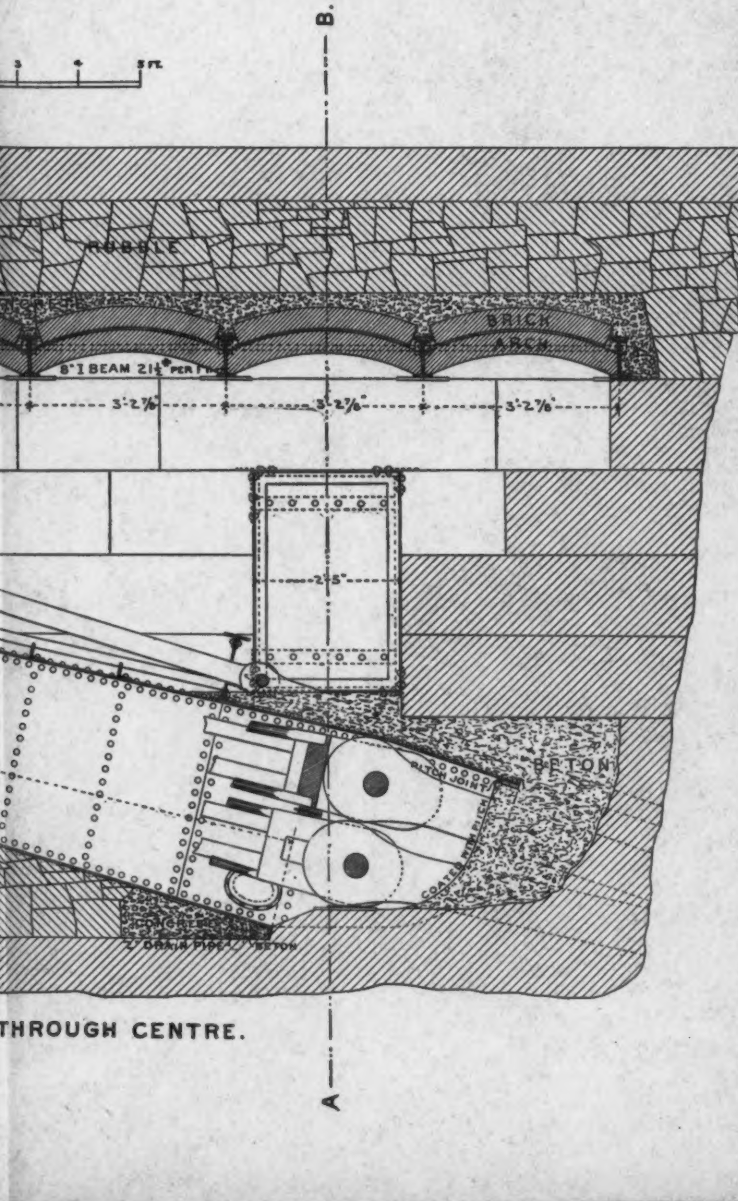


COVINGTON AND CINCINNATI SUSPENSION BRIDGE.
PLAN FOR RESTORATION OF CABLE END.



LONGITUDINAL SECTION THROU
FIG. 19.

PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXVIII, No. 578.
BOUSCAREN ON REPAIRS TO CINCINNATI SUSPENSION BRIDGE.



THROUGH CENTRE.

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(Vol. XXVIII.—February, 1893.)

THE SHONE HYDRO-PNEUMATIC SYSTEM OF SEWERAGE.—DISCUSSION ON PAPER No. 568.*

By F. P. Stearns, Foster Crowell, J. J. R. Croes, J. Foster Flagg, William L. Saunders, William Barclay Parsons, A. Fteley, F. W. Skinner, Rudolph Hering and U. H. Broughton.

F. P. Stearns, M. Am. Soc. C. E.—I have been very much interested in the paper which Mr. Broughton has read, explaining this system of pumping sewage. I have long had a general knowledge of the system and it has always seemed to me to be very well adapted to certain situations; for instance, when I first heard that it was to be used for the sewerage of the World's Fair buildings, it seemed to me a proper system for this place where the ground is level and but a few feet above the lake.

As I have never had any practical experience with the system, I am inclined to take advantage of Mr. Broughton's presence this evening and ask a question rather than attempt to discuss the subject myself,

* See Vol. XXVII, page 659.

and, if questions are in order, I will ask, with reference to the valves shown on the diagram, whether they ever clog. The sewers in our large cities where the "combined system" is used bring down a great variety of coarse things, of which sticks or short pieces of wood are, perhaps, the most likely to clog a valve, while, even in dry weather, when no water is entering from the streets, such articles as cloths and scrubbing brushes find their way into the sewers. Much gravel and sand also enter a "combined system" of sewers.

Mr. Broughton.—As regards the clogging of the valves I have never known the slightest trouble. I can vouch for the following: at a certain place in Chicago, I put a Shone plant for pumping water; the connection to the inlet pipe of the ejector had to be made by a diver, and he did a very bad job. Bricks were carried into the ejector; they passed through the valves and did not stop the work of the ejector at all.

Foster Crowell, M. Am. Soc. C. E.—I should like to ask a question before you sit down. You have given the cost of some of the smaller works; are the figures of the Exposition works available ?

Mr. Broughton.—They are not available, because in a good many of the contracts let there is some rebate. For instance, the people who supply the iron pipe for the sewers have to take it back at a certain time and refund so much money. I can tell the actual cost of the ejectors.

Mr. Crowell.—The details are not so important. It would, however, be interesting and instructive to have the total cost of this large plant for such a specific service, irrespective of the rebates, for comparison with other systems.

Mr. Broughton.—In the cases I have mentioned, I acted as the engineer; but in the case of the Exposition I know nothing of the cost, except the cost of the ejectors themselves, which I am quite willing to give. The cost of the ejectors—there are 52 in number with a united capacity of 17 000 000 galls.—was $72 000. The actual cost of the sewers I do not know. The small gravitation pipes must vary between 80 cents and $1 20 a foot. The air-compressing plant is put there as an exhibit, so I do not know the cost of it.

With reference to cost I might say I have recently prepared a project upon the Shone system for a very large city in the United States, for which one of your members was Consulting Engineer. He told me that there were three or four pumping projects under consideration,

and that my project, when put on the same basis of cost with all the others, was the cheapest. With 140 miles of sewers, the total cost, including everything, turned over in working order, was $1 25 per running foot of sewer. Upon the Shone system it is never necessary to use other—I am talking, of course, of the separate system—than small pipes, because in an absolutely flat country you can get proper grades by sinking your ejectors to the desired depth.

J. J. R. Croes, M. Am. Soc. C. E.—The theory that the separation of the solids and liquids in the filtering tank is facilitated by the agitation consequent upon introducing the unfiltered material at the bottom under a head, and permitting the surface water to flow off by an overflow, does not strike me as tenable. That appears to be an essential feature of the scheme proposed.

Mr. Broughton.—That is what is claimed for this form of settling tank. Such tanks have been in use for several years; they were designed by an engineer named Kinebuhler. I have not seen the tanks in operation myself. The sewage is pumped into the top of the tank; it then falls down a central pipe and is distributed by arms throughout the whole tank. The force with which it comes in sends some of the lighter solid matters up several feet high; these then begin to sink and, in doing so, form a layer of matter which has the effect of partially serving as a floating filter for the other material as it comes in.

Mr. Croes.—Is the theory borne out by the results in practice?

Mr. Broughton.—There have been many papers written describing this action and the tanks have been in use for several years. This is, however, only one feature of these tanks, and is not the especial object of the tank being in that shape. It takes but little room, and any precipitation process may be employed.

J. Foster Flagg.—The author says that a low pressure of the compressed air is generally all that is necessary. Will he state what is the average ordinary pressure used in the system?

Mr. Broughton.—The pressure, of course, depends upon the lift, but it is very seldom that a very great lift is required. The greatest that I know of is at Henley on the Thames, where the total lift is 180 ft., and this is divided into two lifts, it being more economical to produce twice the amount of air than to double the pressure. Fifteen to 25 lbs. pressure in the majority of places is all that is required.

Wm. L. Saunders, M. Am. Soc. C. E.—This subject is one of great

interest to me, not only because it is an important application of compressed air, but in connection with the problem that confronts us in Plainfield as to how to sewer the town. I am very glad to hear, Mr. Chairman, that Mr. Broughton can give us some facts and experiences which antagonize an impression which seems to exist in the public mind as to the dreadful extravagance of compressed air. If we can put a little air compressor on the side of a wall and let it take care of itself, doing such work as this Shone system does, doing it at almost 50% efficiency, it seems to me that this might modify the idea that compressed air is such an extravagant power. In connection with this system, I had occasion several years ago to correspond with Mr. Sturgeon, of London, concerning the plans and projects of Mr. Shone, and Mr. Shone has been of much service to me in the study of compressed air. His tables showing the efficiencies of air compressors are very useful. These tables are now accepted as standard. The pressure which Mr. Broughton has mentioned as that at which the compressed air is used in this system, about 25 lbs., is generally admitted by pneumatic engineers to be the most economical pressure, and it seems to be ample under these circumstances.

In connection with the sewerage of Plainfield, we are now considering the subject, and I presume that our difficulties are similar to those which the Shone people have met in the West. We have a very level country. There are a great many towns between Elizabeth and Somerville and Bound Brook which are growing in population very rapidly, and none of which has any system of sewerage. You go from Elizabeth out to Somerville, passing through Plainfield and North Plainfield, with 20 000 inhabitants, with street railroads and all other improvements, and every fellow is dumping his sewage in the back yard. We have a soil favorable to that condition of things, and, I presume, the condition of the soil and the indifference of the people has led to the continuation of this undesirable system, but the people are now beginning to look into the subject and we have thought of using compressed air in connection with a sewerage system. We purpose to convey the sewage matter to a point just outside the city limits, and possibly the Shone ejector might come in very well to give us the proper level so that we might take in all sections of the city, which covers a large area. I have proposed to carry this to a certain point below the city and there discharge it into a tank, or one or more tanks,

and then admit compressed air into the tanks, the compressed air being furnished from a central station and delivered automatically, in a similar manner to that described in the use of the Shone ejector. But the difference is this, that the sewage, instead of being lifted to a greater level and carried to a discharge point, is simply forced into the ground. In other words, the sewage matter having collected in the tank, the compressed air is admitted on top of it, and a forced filtration is the result. It is proposed to discharge the matter through perforated pipes which connect with the tank near the bottom and which extend radially from the center of each tank. These discharging pipes extend horizontally and need not go over 10 ft. or so under the ground. The water moves from the mountains northeast to a point southwest, and the suggestion is that if we can get the compressed air on the top of the sewage matter and discharge it into the soil, even though it should reach the first water course, we are practically discharging the matter into the ground, and there being no wells near that point, it seems that it might not be unsafe to do so. That is a point on which I would be glad to have, not only Mr. Broughton's opinion, but the opinion of any other member here.

In regard to compressed air in connection with purification, it is a well-known fact that the particles of sewage matter have an affinity for oxygen, and the idea is to treat the sewage by means of compressed air and mechanically agitate it and aerate it, so that when it goes into the ground it is not in such a bad state as when it went into the tank. The sludge can be discharged by means of compressed air by forcing it into the ground, or into a furnace or otherwise. This is the crude idea which exists in our minds at the present time.

Mr. CROES.—It is impossible to condemn too strongly this proposition to pollute the underground sources of water supply by pumping sewage into them under pressure. It is outrageous, and it certainly ought to be prohibited by the State Board of Health from being carried into execution.

Mr. SAUNDERS.—If this danger would exist, is it not true that it now exists? The city is now studded with cesspools which are located near the wells, while the plan which I propose is to concentrate those cesspools at one point outside of the city and in the direction toward which the water under the soil is moving. Experiments have shown that there is a distinct movement in well water from northeast to south-

west, and with filtration tanks located in the extreme southwest, it does not seem to me that there will be any danger due to forcing sewage matter up stream. Besides, there is no reason to think that this matter will reach the water courses which are located below a stratum of clay. It is furthermore reasonable to suppose that there will be a filtration going on as the matter traverses the ground, and, as it had previously had a good dose of compressed air, it is not likely to hurt anybody in case, by any extraordinary provision of Nature, it might travel a mile or so underground. My belief is that it will not travel at all, but will remain in the spongy soil near the surface, losing its liquid matter by evaporation and perhaps nitrification, and in the course of time perhaps becoming clogged by solids. It is a well-known fact that sewage matter contains 2 parts in 1 000 of solid matter; one of these parts is sludge, and the other insoluble matter such as sand, lemon skins, rags, New York *Worlds*, etc. We think there will be no difficulty in taking care of the solid matter even if we have to discharge it from the tank by means of compressed air. It has been suggested that it be discharged into a furnace and burned together with garbage.

Mr. Croes.—If you are going to force water under pressure into a subterranean stream it will work up stream as well as down stream, and the health of Plainfield would not be in the least degree benefited, but on the contrary would be seriously endangered by taking the water from a portion of the sewage and putting it further underground, pumping it and spreading it in every direction, backing up the ground water in the more built-up portions of the town, and also injuring the water of the wells of the outlying portion below on the down-stream side. The pressure of that polluted water into the soil will back up the water, and the effect will extend to a considerable distance away from the pumping station. From the very fact of these underground currents in the soil the result would be that the polluted water would be brought nearer to the surface and the pollution would extend up stream to a considerable distance.

Mr. Saunders.—I must confess that it is not clear to me how this sewage matter can be carried up stream. The proportion of sewage is very small when compared with the body of moving water. You may know that we have under the soil in Plainfield what has been called an "underground river." This is probably nothing more than

the rain water moving through the basin of gravel some distance under the surface. Plainfield is located in a sort of basin and the soil is very porous. There is a layer of clay about eighteen feet below the surface and it is not likely that the sewage will go below this clay. The water supply which comes from a depth greater than 50 ft. is practically inexhaustible, tests having been made pumping night and day large volumes of water with no appreciable diminution of the supply.

WILLIAM BARCLAY PARSONS, M. Am. Soc. C. E.—My experience with Plainfield is that it is entirely possible to run the sewage down to tidewater by ordinary gravitation. I would rather have the sewage disposed of that way than to have it forced beneath the soil into any of the subterranean rivers that the inhabitants of Plainfield believe exist. But to return to the subject of the Shone system. Some two or three years ago I was in the City of Mexico and they were discussing sewerage questions then. There was a talk of introducing the Shone system; was it introduced?

Mr. BROUGHTON.—No, sir; I prepared the project, but it was not introduced because the necessary money was not forthcoming.

Mr. PARSONS.—The City of Mexico is like many other places we have to deal with. Apart from its having no money, those who have been there know that it is founded on the site of an old lake, so that the ground is quite flat and it is almost impossible to get any kind of gravitation system. The only feasible method of disposing of the sewage would be by some mechanical means, either by the Shone system or by some method of pumping. I was interested to know whether anything had been done in this regard.

A. FTELEY, M. Am. Soc. C. E.—Although I do not pretend to be well conversant with the Shone system which I have never seen in operation, I would ask Mr. Broughton whether any provision is made to duplicate the valves or ejectors. We all know that automatic apparatus is liable to get out of order; the valves especially may be clogged and it appears that in any case of derangement of the apparatus an objectionable accumulation of sewage might occur, which, especially in a district which has no natural drainage, would be very objectionable, and would even interfere, after a short time, with the necessary work of repairs. It also occurred to me that, in some cases, a small additional basin could be provided, in the vicinity of the ejectors, to receive, in case of accident, a portion of the contents of the sewers, thus giving time for repairs.

Mr. Broughton.—As an engineer, I admit that no works of man are infallible, and in the case of the Shone system no engineer who has had any experience with pumping machinery for continuous operation would put in one machine only at one place. There are always two machines put in; if anything went wrong with the first, the sewage would flow into the second. If the two machines are out of order at the same time it is time to make a change in the superintendence of the system. I have had an experience of many years with the Shone system, and know of no case where any damage has ever been done by the failure of an ejector. I have known of a case where an ejector has been out of order temporarily, but never where two ejectors at the same station have been out of order at the same time. The bursting of the casting of the ejector itself is a remote contingency. In the majority of cases one can arrange for overflows at the point where the sewage is raised; but that, in my opinion, where machinery is duplicated, is a waste of money. In every work where mechanical operation takes place there ought to be some care and supervision exercised. These are simple machines and require little attention. I might say that their greatest fault is they are too automatic, so much so that the person in charge of them often will not look at them until something—packing, for instance—wears out.

In reference to the City of Mexico, I know every street and alley in that city, and there were no sewer pipes proposed larger than 7 ins. There were to be 33 ejector stations in a city of 420 000 inhabitants, and this worked out vastly cheaper than any system of gravitation they could put in. By this system the pumping stations can be distributed and the saving in the size and depth of the sewers more than pay for the expense of the machinery for pumping.

Mr. Flagg.—In Winona, I understand that, during high water, the Shone ejectors pump against pressure in the outlet sewer. If any foreign articles should get in so as to prop open both valves of an ejector, would not the compressed air from the air pipe, or the pressure in the outlet sewer from high water in the river, force the sewage into some of the houses through the house drains ?

Mr. Broughton.—Everything flows by gravity to the ejector station, and is forced out by the ejector. If the inlet valve was wedged open, the air, when admitted, has a tendency to close that valve, even if there is an obstacle there. But suppose that an iron bar was put underneath

this valve designedly (it could not get there by accident) so that it could not possibly close, then the person in charge of the central station would see that there was an abnormal use of air and would know that there was something wrong. Nothing that can come down the sewer itself can wedge open that valve for the reason that the sewers themselves are smaller in diameter than the valve passages. I do not, of course, wish to infer that there is anything in the Shone system that can wholly obviate disasters.

Mr. Flagg.—Would it not affect the flow?

Mr. Broughton.—It would prevent a flow in the sewer; the water being forced out through the inlet valve would prevent the sewage from entering the ejector, and if that state of things continued long enough, the sewage would back up into the house drains; but that is assuming a very remote contingency. The man in charge of an air compressor can, in a week's time, accustom his ear to tell whether the ejectors are discharging properly. The men in charge of sewerage works ought to have some knowledge of the system employed, and it is their business to know when anything is wrong. I do not see how the valves of the ejector are likely to be clogged when the sewers are smaller than the passage-ways of the valves.

Mr. Flagg.—I should think that if there were 40 or 50 different ejector stations the man in charge could not tell which one was in trouble; it might take him some time to locate it.

Mr. Broughton.—I think that any man in charge, even with 30 or 40 stations, if such a large aperture was open as an inlet valve would find that his engine could hardly keep pace with the waste of air.

Mr. Croes.—The operation of those works would be similar to that of any other complicated system involving the use of machinery. A complete duplicate plant would doubtless be the only means of insuring immunity from accident. But that is not good engineering nor business, nor is it like Nature. The human machine, for instance, is a complicated one and liable to get out of order unless properly cared for. But man has not been provided with a duplicate set of bowels to use in case of disarrangement of the original set. With a well-designed and intelligently managed system of works of any kind some chances must be taken, and there is a better chance of having good work done in the case of a single plant which must be well maintained than with a duplicate plant in which it is felt that it makes very little difference whether any part gives out or not.

Mr. Stearns.—With the knowledge which I have had of the Shone system it has always seemed to me particularly well fitted for special situations. I now have in mind as one of these a place where a ground water supply is taken from gravelly ground on one side of a river, and directly opposite many houses are being built on land so low that the sewage from them cannot be discharged into the system of sewers which provides for other parts of the city ; consequently, the wastes from these houses are disposed of in cesspools and the effluent from them necessarily sinks into the ground and eventually finds its way into the water supply. This seems to be a situation for which the Shone system is particularly well adapted. With a majority of the towns in Massachusetts where the sewerage requires pumping in order that it may be subsequently purified by filtration or otherwise, the sewage can readily be brought to one central station in the lower part of the town and there pumped. In many cases the force main runs with an up grade for a long distance to the point of discharge. An example of this kind is furnished by the sewerage works at South Framingham. At this place the sewage first passes into a large tank which will hold the night sewage and permit the pumping to be done wholly in the daytime. There is an advantage in avoiding night work at the smaller places, as one engineer can do the whole of the pumping, and the sewage reaches the disposal area in the daytime when there are workmen about to take care of it as it comes. It has always seemed to me that a steam pumping plant is particularly adapted to such a situation as this. I would like, however, to hear from Mr. Broughton whether he thinks the Shone system would be applicable in a case of this kind.

Mr. Broughton.—One of the canons accepted by sanitary engineers now is that sewage ought to be got rid of as fast as produced; it ought never to be impounded, as is the case of sewage going into large reservoirs where steam pumps are used. I think I am safe in saying that the Shone is the only sewage pump that can regulate itself. With ordinary steam pumps pumping sewage it is necessary that they should pump at a comparatively uniform rate, and as sewage does not flow at a uniform rate, there must be storage. The result is that if the sewage in the reservoir is a foot lower than it was the week preceding, it has left a film adhering to the sides of the reservoir which rapidly decomposes. That, in itself, is very objectionable, and, moreover, a collection of solids which cannot be reached by the pump,

forms on the bottom of the reservoir and has to be removed by manual labor.

Where sewage is brought to one station, the sewers in a town of any considerable size must necessarily be large and in the majority of cases deep, and if the sewage is stored in a reservoir it is apt to produce sewer gas which is distributed all over the city. The only way to render a sewerage system perfect is to get rid of everything as fast as it collects.

I have seen a great number of ordinary sewage pumping stations, and I have never seen a station where they had not to resort to screens. These screens are constantly getting clogged up. In a sewage pumping station in Europe, which was designed by a man eminent in his profession, I know that those screens have to be cleaned three or four times a day. Take the case of Preston, England, which is a place where some of the finest steam pumps are manufactured. The authorities of Preston, although the majority of them are men who are interested in the manufacture of pumps, selected the Shone system for the reason that the pumping stations are in the residential district and this system disposes of everything as fast as it comes along, and is absolutely inoffensive.

In regard to the case referred to, where there is a pumping station and a few houses on the other side of the river which could not be connected with the main system, it would be a very simple matter to put down an ejector station to drain those houses to it and lay a small air pipe from the pumping station to the ejector. In this case there would be no extra cost for attendance, because the small attention that the compressor would require could be given by the man who looked after the pumping engines. Referring to the relative efficiency of pumping with steam and compressed air, in dealing with water you cannot get the same efficiency with compressed air that you can with steam pumps; but with sewage you can, for the reason that the lift in the valves of sewage pumps have to be greater, to allow the thousand and one things to pass that come down a sewer; the slip is greater than when pumping clean water. For lifts where low pressure is employed, I should say you can get just as high an efficiency when pumping crude sewage by means of compressed air, as you can with the best steam sewage pumps.

F. W. Skinner, M. Am. Soc. C. E.—I would like to ask for further

explanations from Mr. Broughton. As I understand, his great objection to the use of steam pumps is that it is almost impossible to control them for variable intermittent flow. Now it is well known that, especially in this city, there are a very large number of mechanical systems, particularly in large buildings, where water of condensation from steam apparatus, or water collected from various sources, is received in tanks and pumped out by steam pumps, those pumps being regulated by automatic governors that are usually operated by floats following the water level, and directly controlling the steam supply.

The result is that ordinarily the pump works very slowly under a little constant steam supply which is immediately increased and the speed raised if any sudden or augmented flow of water raises its level in the float chamber. I do not know that there has been any occasion to adapt this arrangement to large pumps, but it would be only an extension of simple and efficient apparatus to larger duty and could hardly offer serious trouble to practical designers.

Mr. STEARNS.—There are some points made by Mr. Broughton which I cannot fully agree with. He speaks, for instance, of the efficiency of the Shone ejectors as compared with steam pumps. I notice in his paper the statement that Prof. Unwin made some tests on ejectors and the percentage of useful work obtained, after allowing for all losses, was 48.9%. I will ask if the percentage given is meant to indicate the relation between the indicated horse power of the engine and the actual work done in lifting the sewage.

Mr. BROUGHTON.—I mean the efficiency of the whole system.

Mr. STEARNS.—Several years ago I had occasion, with some other engineers, to test the steam plant of the Boston Sewerage Works and we found that an indicated horse power was developed from 1.35 lbs. of coals per hour, and that the efficiency of the pump was 80%, so that there was only a consumption of 1.70 lbs. of coal per actual horse power per hour. These pumping engines gave a duty on these tests, of 122 000 000 foot-pounds per 100 lbs. of coal. Even with low lifts the use of pumps may be very economical; for instance, at Milwaukee, they use centrifugal pumps with a lift of about 15 ft., and get in their ordinary work a duty of 58 000 000 and have obtained from tests 65 000 000 to 68 000 000.

Mr. Broughton also speaks of the necessity of having a reservoir, which he considers an unsanitary feature. In the Boston system there

is no reservoir to pump from with the exception of pump wells of limited capacity and the main sewer. Several years ago when I had immediate charge of the works, it was the custom to let the sewer fill two-thirds full in the afternoon in order to furnish sufficient sewage to pump during the night, but at the present time the night flow is so large that there would be no difficulty in pumping the sewage as it comes without any considerable fluctuation.

I will say in conclusion, that I was very glad to hear Mr. Broughton's views as to the general applicability of the Shone system, and, as I understand his statement, he would use it in a majority of cases in preference to the more common method of pumping by steam.

Mr. Broughton.—It was my intention to convey the idea that it was necessary to have a reservoir to allow the sewage to collect in the neighborhood of the sewer when ordinary steam pumps were employed or else use the main sewer as a reservoir. Notwithstanding that steam is used to generate compressed air I claim that it is economical for low lifts to raise sewage by compressed air. I am very glad to hear your remarks to-night because I have tried in various parts of the world to get reliable results of over 50% efficiency with ordinary steam sewage pumps, and I am interested to hear that the Boston pumps will give an efficiency of 80% because I did not think such a thing was possible when pumping unscreened sewage. I know of some very large pumps that pump sewage with a loss in slip alone of 22%; they pump sewage that is very roughly screened. Eighty per cent. is not a bad efficiency for pumping water; of course, I know that one can get higher. In pumping by means of compressed air it is possible with a lift of 20 ft. to get a duty of 79 200 000 lbs. I wish to be put on record that I do contend that for low lifts you can pump unscreened sewage with compressed air as economically as you can with steam, the loss in producing air at low pressures being very slight. You must admit that even at Boston stoppage in pumping takes place; the sewage is not got rid of as fast as it is produced; that is more or less detrimental according to what impounding there is. In some places everything can be brought to one point where no big sewers are required, and then it becomes a question to an engineer whether he will use direct acting pumps or compressed air. The best application of the Shone system is where you use power at several points where the saving is in the depth of cutting and in the size of the pipes. Other things being equal, a system is the bet-

ter the smaller the pipes are, provided they are large enough to take the sewage.

In regard to Mr. Skinner's remarks, I am perfectly well acquainted with such devices as he speaks of; my experience has been that they get out of order very easily. I do not say it is impossible to apply such devices to large pumps pumping several million gallons per day, but they have not been so far, I believe.

Rudolph Hering, M. Am. Soc. C. E.—What is commonly known as the Shone system of sewerage is nothing more or less than the application of a certain mechanical contrivance for lifting liquids. The merits of this system, it seems to me, should therefore be discussed in comparison merely with other means of lifting sewage, and with whatever incidental effects such lifting may produce. I notice that many advantages which are claimed by the author of the paper must be equally credited to other sewerage systems. They should therefore be eliminated from the present discussion.

My first acquaintance with the Shone ejector was in the summer of 1880 when I examined one in Wrexham, England, and saw its working. I was then impressed with certain advantages of this appliance that seemed to me unquestionable, and I so reported at the time.* Since then I have been observing its further introduction and the reports on both sides which have been made regarding it. In view of a possible application of the same in another locality, I was recently again obliged to examine a number of ejectors, built for the sewerage of the World's Fair grounds in Chicago. I may briefly sum up the impressions which I have gained and the conclusions at which I have arrived at the present time regarding the use of the Shone ejectors, as follows.

One advantage of the ejector over a reciprocating pump is its greater simplicity. It has fewer parts; it requires no finished surfaces nor carefully constructed valves which are exposed to considerable wear. Nor does it require screens or sludge pits, but will allow the ordinary rubbish which enters a sewer to be lifted with the same ease with which it will lift the water. As compared with centrifugal pumps, the ejector will operate with the smallest flow of sewage, while the former requires a certain minimum amount, which is usually not small, and, to be of the greatest advantage, a comparatively uniform flow. The ejector simply varies the rate of its pulsations in accordance with the amount of sewage delivered to it.

* See Report of the National Board of Health, 1881.

From what I have seen and heard and can judge, the sanitary efficiency of the ejectors is quite as satisfactory as that of pumps. In fact, if there is any difference, it is greater. The pulsating flow caused by the ejector is liable to keep the sewers naturally cleaner than the more uniform flow of the same amount of sewage, which is the condition where the common method of sewage pumping is resorted to.

Other advantages may be mentioned to be the facility with which small districts, requiring the pumping of sewage, can be added to the general system, because no constant attendance would be required other than that in the central pumping station. It is further claimed, and I think the advantage is worth mentioning, that the flushing water required to keep the system of sewerage clean is reduced by the Shone method of pumping.

The main advantage, however, from a financial point of view, is the fact that deep excavations can be entirely avoided by the use of these ejectors. Where deep excavations are expensive, from the fact that they would require tunneling, or deep sheeting in water-bearing soil or quicksand, or in other treacherous ground, it may be less expensive to pump the sewage by ejectors at one or several points along such a line than by making the excavations or tunnels.

In criticising this system of pumping a great many objections to it have been made, but only the following, I think, are worthy of serious consideration.

What has been said about insufficient ventilation is hardly worth mentioning, because it is just as practicable to accomplish it in the same way as in any other system. If there is a difference, I think it is rather in favor of the ejectors, because the liberated compressed air introduced by them into the sewers somewhat aids the circulation and exchange of air.

If we consider the ejector as an automatic machine which will run itself for an indefinite time without attention, we may say that in comparison with other pumping machinery, which is under constant supervision, it has the disadvantage of possessing movable parts which are liable to get out of order and thus prevent it from acting. The gradual loss of oil in such parts, or its gumming in extremely cold weather, are undoubted disadvantages, if we expect the machine to be automatic.

A serious disadvantage of the ejector, however, is that, should it become inoperative at any one of the stations, either by a break in the

air pipe supplying it with power, or by a mishap to the ejector itself (remote but possible contingencies), there would be no outlet for the sewage of that district and it would rise until it could obtain one, either into an over-flow sewer, if such were practicable, or into cellars, or finally upon the surface of the street. On the other hand, to provide for mishaps in a central pumping station there always is, or should be, a duplicate pump equal in capacity to the largest at the station, and there are persons present continuously, to give warning or at once to repair the damage. I think this disadvantage should be considered to increase with the area of the district and the number of ejectors.

The greatest disadvantage, however, which in my opinion prevents an extensive introduction of the Shone ejectors for the purpose of lifting sewage in cities, is the greater cost of the same under the usual conditions presented. It consists partly in the cost of the ejectors, partly in the cost of the special pipe conveying the compressed air to them, and partly to the loss of power due to its transmission to a distance before it is used, instead of being applied directly to lifting the sewage, as in reciprocating and centrifugal pumps. I have seen a statement that official tests in Rangoon, India, showed 67.4% of the engine power to be wasted in the Shone system. I do not wish to consider this as a fair result by which the loss of power by the ejector system is to be judged. But it cannot be questioned that the loss will be greater by the intermediate use of compressed air than where steam is applied directly to the pumps.

We should likewise consider the fact, in judging of the availability of this system, that the reported success from other countries does not necessarily mean a success in our own, even if the physical conditions are the same. We should not forget to take into account the different ways in which, as a rule, our municipal, and particularly our sewerage works, are managed. As we generally devote much less time and labor per mile to maintaining such systems than, for instance, they do in Europe (somewhat to our discredit), we should endeavor to recommend to cities the simplest system for the purpose of successful management.

In conclusion, it may be said that in considering the Shone ejectors as a means of pumping we should be governed mainly by the cost. If the cost is less I should not myself hesitate to recommend them, and

feel that under careful management they will give entire satisfaction. When the cost, as compared with other methods of pumping sewage, is about equal, the decision should, I think, be rendered mainly on the basis of the comparative simplicity and reliability in the working of the respective methods of lifting which are available for the particular case. It seems to me that the application of these ejectors for lifting sewage or water from the cellars of our modern large buildings will be the most successful field in which they can be employed. Further, when the ejectors can be of easy access from a central station in cities or parts of cities, and when a system of rigid inspection can be enforced, I think their application will likewise be successful, when less expensive than other methods of pumping.

The present extensive application of the Shone ejectors on the World's Fair Grounds should give us sufficient experience in this country to judge of the merits and demerits of this ingenious contrivance in its application to extensive areas. I trust that we may be able to obtain in due time from the engineers in charge, a detailed record and account of the operation of the ejectors from the time they were placed in position to that of the closing of the Fair.

Mr. Broughton.—It has been a satisfaction to me to hear the remarks of Mr. Rudolph Hering upon the Shone system. Comparing this system with other methods of pumping sewage, he alludes to nine points and gives the advantage to the Shone ejector in six of these. With regard to the disadvantages, in his opinion, I would like to make a few remarks.

I take exception to his statement "that the Shone system of sewerage is nothing more nor less than the application of a certain mechanical contrivance for lifting sewage." The manner in which the mechanical contrivances in the Shone system can be used permit of many important features in the sewers themselves being obtained, which are impracticable upon the central pumping station plan. Take, for example, a practically flat city where the sewage has to be pumped; in such a case to collect the sewage at one central pumping station by means of sewers laid at good grades might not be feasible at all, and in any case would entail large sewers and deep excavations. On the other hand it would be a simple matter to lay small and comparatively shallow sewers, converging to several ejector stations, which can be operated from one power station. The same results, as far as the sewers are

concerned, could be obtained by having several independent pumping stations, each with its own staff of attendants; but that, I think, may be called impracticable.

The ejectors are, or should be, placed in duplicate at each station, and in the event of failure on the part of one ejector, the second comes into play automatically; so in that respect the duplicate ejector has a slight advantage over the duplicate pump at the central station.

A break in an air pipe is a possibility, but a remote contingency, and such a break would instantly be discovered and easily rectified. In my opinion there is no more probability of an air pipe breaking than there is of the main sewer leading to a central pumping station failing, and in the latter case the effect would be more disastrous.

The ejector is an automatic machine, but that does not imply that it should not receive any attention. Some ejectors (working underneath streets) that are at present under my supervision are inspected once a week, and even with a temperature for weeks varying between freezing point and 15° below zero, there has been no gumming in the working parts.

In Mr. Hering's opinion the greatest disadvantage in the Shone system is the greater cost of the system under the usual conditions presented. I contend that the cost of the Shone system is generally less than any other system where pumping has to be resorted to, and my contention is based upon the actual cost of works executed, and upon comparative estimates made for projects upon the Shone system, and upon the central pumping station plan, under the same conditions.

Upon the Shone system, ejectors and air pipes may be considered extra requirements, as may be reservoirs or large main sewers, screens and sludge pits on the central pumping station plan. The items, however, which more than any other govern the cost of a sewerage system are the depths of the excavations and the sizes of the sewers, and these need never be excessive on the Shone system, while they are often so, of necessity, in conducting the sewage of a city to one point. The saving in these items alone frequently more than pays for the ejectors and air pipes.

With regard to the loss of power due to transmission of air to distances, there is practically none. By using air pipes of moderate diameter only, the velocity of the air can be so adjusted that the loss by friction in transmission is only 1% of the absolute initial pressure per 1 000 ft. of pipe.

With regard to the efficiency of the Shone system at Rangoon, there are 25 ejector stations and 7 miles of air pipes, and the tests made showed an efficiency of 33% with expenditure of $\frac{2}{47}$ lbs. of coal per I. H. P. per hour. This is an efficiency practically unattainable with the best steam-pumping installations if placed at the sites of the ejectors and doing similar work. Moreover, the tests were made early in 1891 when but few connections had been made with the sewers, and the engineers who conducted the tests state in their report :

"The power required for the ejection of the present quantity of sewage is so far below the capacity of a single engine and boiler that the efficiency cannot be otherwise than low as compared with what may be expected when greatly increased quantities have to be dealt with."

Referring further to the remarks of Mr. Stearns, I would say that the efficiency of 48.9% obtained by Professor Unwin is the relation between the I. H. P. of the compressing engine and the work done in lifting the sewage, and is the combined efficiencies of the compressing engines, the air mains, and the ejectors.

I have, through the courtesy of Mr. Stearns, had an opportunity of reading a description of the Boston sewage pumping plant, and the results of some duty tests conducted under the direction of the City Engineer.

It is stated in the description of the plant :

"On reaching the pumping station at the sea coast the sewage first passes through what is called the filth hoist. This is a subterranean structure containing five chambers, in four of which cages or screens are hung so as to be raised and lowered by steam-power."

The results obtained at Boston do not prove anything against my statement that I do not think it possible to get an efficiency of over 50% with steam pumps pumping unscreened sewage, in the way the ejectors do.

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ROAD CONSTRUCTION.—DISCUSSION ON PAPER No. 565.*

By EDWARD PRINCE, E. W. HOWE, WILLIAM H. GRANT, FOSTER CROWELL, LATHAM ANDERSON, W. C. OASTLER, P. CALLANAN, EDWIN MITCHELL, SAMUEL L. COOPER, E. E. R. TRATMAN, H. M. WILSON, W. S. BACOT, O. SAABYE, J. F. O'ROURKE, CALVIN TOMKINS, JAMES HALL, E. P. NORTH and JAMES OWEN.

EDWARD PRINCE, M. Am. Soc. C. E.—While there are many things in the paper by James Owen, M. Am. Soc. C. E., on the "Controverted Questions in Road Construction," which are no doubt entirely correct, there are some things with which I cannot agree. In what practice and observation I have had, a 15-ton or 20-ton steam-roller for the sub-grade, the foundation and the top-dressing, by far surpasses in efficiency any, say, 5-ton horse-roller. The pressure of the steam-roller per inch run is so much greater that on the sub-grade, weak spots are found and consolidated which would not be found at all with a horse-roller.

* "The Controverted Questions in Road Construction," by James Owen, M. Am. Soc. C. E., Vol. XXVII, page 603.

On the subsequent courses, that the best work is done with the steam-roller is evident from the fact that in all large cities of the world, of which I have any knowledge, where a foundation is to be prepared in the usual way for an asphalt or a block pavement, the steam-roller is used and thought to be almost indispensable. The testimony of the best and of most of the engineers of the world, as well as the great and increasing manufacture and sale of steam-rollers, is more convincing than anything else.

In regard to repairs, Mr. Owen seems to have discarded the idea that a "stitch in time saves nine," and ridicules the "tradition of other climes." Although it is perhaps unfair to compare the methods of constant repair on a railroad with its skilled section men and careful watchfulness and repair of a country or city road by a small gang of men who know what, when, and how to do; yet the two cases are alike in this—that in either case the efficiency of a considerable length of line is very much lessened by a very few serious defects along that line; alike in the fact that no wagon road or railroad track of any considerable length ever existed which would wear out, evenly or "uniformly," its entire length, or for any considerable portion of its length, so that it would be economy to omit repairs or "patching" until it became necessary to make a new road or roadbed. Storms, frost, thaws, settlements, holes or sinkings visit wagon-roads and railroads, and generally immediate attention proves a matter of the greatest economy. I have never seen in any clime a gang of men whose sole duty it was to repair, and thought them out of place. I have always regarded the existence of these gangs as evidence of the thrift, prosperity and good business economy of those who hired them.

This remark applies to wagon-roads, streets, railroads, water works, gas works, levees and every other work with which the great public has to do. Of course, it goes without saying, that if it is proper and wise to have men to repair anything, they should have something to repair with. From this follows the wisdom and propriety of "piles of stone on the highway convenient," so that the repairers would not have to obtain the material for repair at a time when it would be very difficult to obtain it, and haul it when obtained over roads rendered impassable by the elements.

It seems to me somewhat improper to ridicule the methods adopted by the ablest engineers of other climes, notably those of France

(*Ponts et Chaussées*) and Germany, by calling these methods and their literature on the subject "tradition," while our roads in this country are generally no more to be compared with their roads than is the road which the Arkansas traveler found, to be likened to Pennsylvania Avenue, Washington City. What Mr. Owen says in another place about repairs can be fully endorsed. He says, "As the construction of a road is incidental, and the repair is perennial." I cannot conceive of a word which could be used and which would more clearly express what has to be done to a road to keep it in condition.

"1—Lasting or continuing, without cessation, through the year."

"2—Perpetual, unceasing, never failing"—(Webster).

This seems to coincide with, and properly expresses, the practice in those countries where they have good roads.

In regard to packing, the best material I have ever used has been clean, sharp sand, well worked into the interstices with the hose. This is not always obtainable, and when it is, water is not always convenient; but the rains and heavy rolling will finally make sand and broken stone very compact and homogeneous. When sand cannot be obtained, it is likely that the next best thing is any fine road material which will not decompose or readily wash away.

In regard to wagon wheels making a road, it has been my observation that, except at road crossings, wagon wheels with the usual narrow tires do more damage to roads than anything else.

Every wagon driver seeks to drive on the smoothest place, and the result ordinarily is that a depression or rut is formed along the line of the travel of the wheels. The wagons of a locality are usually of the same gauge, and this helps to form ruts.

This uniformity of wheel gauge and usual narrowness of tire width is disastrous to roads.

Broad Tires.—It is perhaps only necessary to allude to the fact that the history of the wheels of vehicles is a very interesting one, and that vehicles have been in use a long time.

This use has become so great in modern times that in pleasure vehicles alone there are now names for about forty different kinds. Anciently, the wheels were wide, made of wood, strong and clumsy. With the introduction of iron and steel the wheels were made much lighter and much stronger, and to-day a steel-tired wheel, with its hub and spokes, is what might truthfully be called a beautiful and wonder-

fully well-executed work of the highest kind of talent and skill of the mechanic's art.

Americans are justly very proud of their success in this direction and have certainly combined in a remarkable degree beauty with strength, compactness with comfort, and stiffness with safety. The improvements in these directions have led to the narrowing of felloe and tire width, in what may be called traffic road wagons. So that, while in olden times such width ranged from 3 to 10 ins., now in the United States (with very few exceptions) wagon tires are only 2 to 2½ ins. in width.

It is very likely the modern cheapness of iron and steel and improvements made in the manufacture of the same have had something to do with it. Now a set of tires costs a nominal sum as compared with former prices.

The tires of most springless traffic vehicles are now so narrow in this country generally, and the loads which they can and do carry are so great that the absolute and speedy destruction of the highway follows. A four-wheeled wagon with a load on each wheel of 1 ton (2 240 lbs.) has a pressure per inch run of 1 120 lbs. This is in excess of the usual pressure of a steam-roller.

The wheels of wagons in this country being purposely made to the same gauge for a large extent of territory, the result is that the wheels will generally follow one another and wear out and break through almost any constructed road or pavement, because the pressure and wear is not spread over a larger surface. It is absurd to suppose that the driver will seek in any way to improve the road; he seems to think that his mission is to destroy the road, and he deliberately proceeds to do it.

Only the positive fear of going clear through, breaking a wheel or sticking, will induce a driver to pull out of a rut in a road, which rut he and his fellows have succeeded in making after an effort of several weeks with the assistance of the weather. It is astonishing that while there is so much literature on the subject of roads and road construction, very few of the writers on roads have anything at all to say about the narrow tires which destroy them. If I were to start out on a road with a pick and a shovel and tear up a road in a few places, I would be arrested and punished; but another man can start out with an overloaded knife-tired wagon attached to six horses, in weather just suited

to his destructive mission, and he will do ten times as much injury to the same road as I did, and the community is in full sympathy with him. This same road fiend will keep out of his fields with his knife-edged wheels in such weather because that would cost him money, but the destruction of the highway costs him nothing directly.

It is now proposed to spend, say, two or three hundred millions of dollars in this country to make good roads. It would seem that the object sought is so desirable that good roads would be cheap at double that figure. But while we are doing this, shall we have no thought towards keeping these roads good? No law against the arch-destroyer of these roads and pavements—narrow tires?

Every argument in favor of good roads is an argument in favor of keeping them so. If this is true, it would be the part of wisdom to prevent as far as possible improper uses which destroy roads. Assuming that narrow tires are injurious to roads and streets, and that it is desirable to require the use of broad tires as in other countries, there are two questions remaining: First, how wide should the tire be? Second, what kind of legislation is needed? It is generally, if not universally admitted, that a $2\frac{1}{2}$-in. tire wears twice as much as a 4-in. tire. That on a paved street or hard Macadam road the resistance (traction) is independent of the width of the tire, when this quantity exceeds, say, 4 ins.; that when the tire is between 2 and 4 ins. for heavy loads and low speeds, the broader tire will have proportionately less resistance. Telford's rule was 1 in. of tire for every 500 lbs. weight on the wheel. A less width of tire is allowable for vehicles with springs than for those without.

Mr. Potter in "Good Roads" recommends the following table:

Load on each Wheel.	Wagon without Springs.	Wagon with Springs.
1 000 to 1 500 lbs.	4 ins.	$2\frac{1}{2}$ ins.
1 500 to 2 000 lbs.	5 "	$3\frac{1}{2}$ "
2 000 to 3 000 lbs.	6 "	4 "

Owing to the difficulty in getting at the weight of loads, it would probably be better to make the minimum width of tire allowable on traffic wagons (to be used on public roads or streets) 4 ins. Then make a scale of tire-widths from 4 ins. upwards, based on the strength and capacity of the vehicle to haul a load on as smooth a road as

asphalt; in all cases, however, allowing a little less width of tire, say, ½ in., on vehicles with springs.

Wagons with strength and capacity to haul a steam boiler, or casting, weighing, say, 10 tons, should have a tire-width of at least 6 ins. It would also be well to require all traffic vehicles used on public roads or streets to have the forward axle shorter than the hind axle by twice the width of the tire of such vehicle. In regard to legislation, there is not much precedent in this country. The State of Michigan has a law giving rebate of one-half the road tax to the user of wide tires. Springfield, Illinois, and Davenport, Iowa, have wide-tire ordinances.

It is probable that each State should frame a law defining the width of tires and trackage of wheels to be used on all public streets and roads in such States. It would be very desirable (though not at all indispensable) that these laws should be alike, and this could only be effected by a general convention of delegates representing all the States and by the different legislators adopting, as far as possible, the final recommendations of the national convention.

In view of the subject of broad tires, and a careful examination of the literature referred to below, I am led to submit in conclusion: that the tires of traffic vehicles in the United States are too narrow; that the injury which such tires inflict on public roads and streets is enormous and outrageous; that immediate legislation should be had, and laws and ordinances made, strong enough to correct the evil wrought by thin wheels; that it will be a very difficult and expensive undertaking to construct any road or pavement which cannot be destroyed by unlimited loads on vehicles with the narrowest tires.

That, on the other hand, it will be very easy to construct good roads and good pavements and keep them in repair when the tires of traffic vehicles are so constructed as to become preservers instead of destroyers of highways; that as a matter of economy in the expedition of traffic and the maintenance of highways and pavements, the regulation of the width of wheels comes first, and yet goes hand in hand and shoulder to shoulder with the laudable effort made now in this country to improve the unnecessary, unprofitable, unwise, and deplorable condition of our country and city thoroughfares.

It is a shame and a disgrace that while the people of the United States have no doubt earned a reputation as among the very first in

most of those things which constitute the highest civilization, they are now far behind almost the entire civilized world in the matter of the expedition of vehicle traffic.

With an awakened public sentiment, and thorough and prompt action in the above direction, we may soon look for, and reasonably expect an improvement in our nation, and in the prosperity, peace, comfort, happiness and economies of all its people.

E. W. Howe, M. Am. Soc. C. E.—I cannot agree with Mr. Owen as to the desirability of patching. It certainly is desirable to build a road so that it may wear down uniformly, and the whole surface come to repair at once, but I have never seen such a road, and if any one can build one he must be a lineal descendant of the deacon made famous by Dr. Holmes who built his vehicle—

> " . . . . in such a wonderful way,
> That it run just a hundred years to a day,"

and then went to pieces—

> " All at once and nothing first,
> Just as bubbles do when they burst."

Even if a road could be built so as to be equally good at all points, the causes of its destruction will vary; changes of grade, intersection with other roads and private driveways, greater exposure to wind and sun in some places than in others, curves where travel takes the inner side, and many other causes, will make the wear uneven. If a road is left until the whole surface needs repairing, some portions will be in a very bad condition.

On the Boston Park drives the "stitch-in-time" method which Mr. Owen deprecates is followed; as soon as a spot shows signs of wear it receives attention, and the repairs consist simply of spreading a few

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NOTE.—The writer begs to refer those who desire to make a fuller examination of this interesting subject to the following: A Circular "To Those Who Love Rhode Island," Bowen & Southwick, Jr. "A Move for Better Roads," compilation by Prof. Lewis M. Haupt, Phil., page 210–240–288. "Pavements and Roads," compilation by E. G. Love, and reprinted from "Engineering and Building Record," page 252, 279, 372 and 405. "Pavement and Municipal Engineering," Indianapolis, Vol. 3, No. 2, page 40; Vol. 3, No. 4, page 93, 125, 126; Vol. 3, No. 7, page 179. "Good Roads," journal edited by Isaac B. Potter, N. Y. City, Vol. 1, No. 5, page 243; Vol. 2, No. 2, page 90. "Encyclopædia Brittanica," Vol. xx, page 584, "Roads." "Spon's Dictionary of Engineering," Roads, page 2775. "Highway Construction," by Austin T. Byrne, C. E., page 271–272.

coarse screenings (*i. e.*, stone which has passed through a screen of $\frac{3}{4}$-in. mesh and been retained by a screen of $\frac{1}{2}$-in. mesh) over the spot. It may be that only a shovelful is used in one place. This makes so little show that the spot is not avoided by those driving, and in two or three days the screenings become incorporated with the surface and all evidence of their use or of the previous damage disappears. After severe storms and in the early spring more material is required and larger areas have to be covered, but the covering at any one time is so light that a few days' travel works it down to a smooth surface. Hollows in the surface are not allowed to form.

We have roads that have been in use for nine years which are in as perfect condition as when first opened to travel, and, while heavy teaming by the public is excluded from park drives, those first built have been subject to a great deal of heavy traffic incidental to the work of park construction, and the pleasure-driving has been very large in amount. These roads have never had a pick struck into them nor a roller, either horse or steam, used on them since they were first finished; nor has any portion of them been closed to travel a single hour on account of repairs. It should be said that these roads have been well sprinkled and kept clean, which, of course, adds greatly to their durability. The cost of repairs, not including sprinkling and cleaning, has varied from 1 to $1\frac{5}{16}$ cents per square yard per year. This would undoubtedly be too high a cost to be practicable for country roads; but it should be considered that our standard as to perfection of surface is a high one and that city labor is the most expensive; on the other hand, on the country roads coarser stone could be used for repairs which, with the cheaper labor and teaming, would greatly reduce this price. I have no figures giving the cost of resurfacing, but if the cost per square yard of picking up and resurfacing one of our roads (including in many cases the repaving of gutters and resetting of curbstone) were divided by the above-mentioned cost for repairs, I am sure that the number of years represented by the quotient would be greatly in excess of the life of any Telford or Macadam road, subject to the same traffic, on which nothing had been expended for repairs.

If any one watches the process of the deterioration of the surface of a broad Telford or Macadam road, such as would be built in the city, he will not find that the destruction is due to the formation of ruts, but that it is caused by the formation of somewhat circular depressions;

these depressions, at first but a few inches across, and a small fraction of an inch deep, retain the water left by the sprinkler; this water does not have time to soak away before the cart comes around again; the bottom and edges of the depression become softened by the water and every wheel that runs across it enlarges the defect, so that in a short time a hole is formed that requires a large amount of material to fill. Screenings in such a quantity will not pack under traffic, and coarser stone, if left loose, will be scattered over the street by the wheels and the horses' feet. The only remedy is to pick up the surface, add new material and thoroughly ram or roll it. All this would have been saved by the use of half a shovelful of screenings when the first sign of wear appeared.

A few words as to the steam-roller. I think with Mr. Owen that a better bonding of the stone can be obtained with a light roller, especially with the sectional grooved-roller, but the trouble is the time and expense required. I do not think he is quite fair in using the comparison of 2 tons 100 times as against 20 tons 10 times. My experience is that the steam-roller travels faster than the horse-roller and does not have to rest so often, so that the 20 tons should be taken 100 times in his comparison.

Screenings.—As before stated, I find, as I think, good use for screenings; but the economy of their use will depend upon circumstances. Nothing, it seems to me, can be better for finishing the surface of a road than the screenings from the stone crusher; but, of course, it would not be economy to grind up stone into screenings alone. In most places, however, where roads are being built, or where they are being repaired, as of course they must be, either by patching or resurfacing, stone is being crushed and a large amount of screenings is produced. This material, it seems to me, is too valuable to be thrown away. Where transportation for a long distance enters into the case, it may be a question whether a material cannot be obtained nearer by which will answer nearly as well.

The matter of sprinkling is, I think, managed very badly in many cities. This is frequently let out by contract for the season, and the contractor's interest is to keep the dust down with as little labor as possible. He therefore uses a sprinkler with large holes, so that he can give the road such a soaking that it will not become dry for several hours. The effect is very much the same as would be that of hard

showers occurring two or three times a day; the road just after sprinkling is a mass of mud, the covering becomes softened and loosened, is picked up by the wheels and thrown over the carriages and their occupants, very much to the injury both of them and the road. If a fine sprinkler is used and the road gone over frequently, the latter can be kept as smooth as a floor, and there will be no mud. The cost of sprinkling will undoubtedly be greater, but the road surface will be saved and a large reduction made in the cost of repairs.

William H. Grant, M. Am. Soc. C. E.—I have read the interesting paper by James Owen, M. Am. Soc. C. E., on "The Controverted Questions in Road Construction," and the discussions upon the same, and have made the following notes thereon.

The paper itself is a valuable contribution on the road question of the day by an expert road-maker of long experience, but I will only, at present, refer to some points brought out by the discussion. I notice, first, a disparaging criticism of the Central Park roads by Mr. E. P. North which does injustice to the design, construction and maintenance of those roads. He speaks of "an unreasoning application of principles of construction," a "glaring instance" of which he charges upon the Park roads.

The architects of the Park, he says, "had apparently read, in the books attainable, that moisture was the great enemy of wheelways," etc., and the consequence was a system of roads devoid of shade and open to the sunlight to counteract the difficulty. This indictment is not followed by proof sufficient to establish its accuracy.

I believe I may say in behalf of the architects that the planting of the Park was not governed by any considerations of either sunlight or shade in connection with the roads. The roads were for pleasure travel, and the planting in their vicinity was an æsthetic matter, designed to afford agreeable views of the adjacent landscape, broken, as far as practicable with good taste, by groups of trees here and there. It would have been shocking to pleasure-seekers, had it been otherwise—a bleak track through a vacant desert on the one hand and a gloomy chapparal of shade on the other.

While absolving the architects from an unkind imputation, I trust I may be pardoned for the egotism of attempting my own justification in the matter. The roads, as regards mode of construction, materials and supervision, were mainly left to me as superintending engineer of

the Park, under the approval of the architect-in-chief and (after his retirement) by that of Hon. Andrew H. Green, comptroller of the Park. The maintenance of the roads was also left to me for some time after the completion of the work. I think I may claim that "an increasing application of the principles of construction" did not characterize my conduct of the work. This could easily have been ascertained by Mr. North if he had availed himself of the opportunity of studying the subject. The results of the work alone ought to go far to exclude a charge of "glaring defects in it." It is no distortion of facts to say that, from the time of opening the roads to travel to the present day, through an interval of many years, they have been regarded by the public with admiration, have received many encomiums and have been found worthy of imitation by engineers in many other localities.

If better roads for the purpose intended have been made they have escaped my observation; and if any strictures have arisen in regard to them, those of Mr. North are the first I have seen.

"The great enemy of wheelways—moisture"—was duly considered, but it was not thought necessary to resort to unbroken sunlight upon the roads to counteract it. A better way was believed to be good construction, selection and judicious manipulation of materials, and thorough drainage. I am not aware of any fatal mistake in this. Is there not a little confusion of terms as to this? If mere moisture is such a great enemy, why complain of sunlight?

Ordinarily moisture is not an enemy, but a necessity, except as it aids at intervals the effects of frost. Water in excess is an enemy, and great pains were taken to deal with it on the Park roads by attention to drainage. The consequence was, while the roads were under my supervision, that after each passing shower the water soon disappeared and was carried off in the drains, leaving the road surface, in a few hours, in the previous condition for agreeable travel. I will remark in regard to "the reading of books," that all information from the works of practical road-makers, and especially those of England and France, was availed of; and, if space would permit, I could describe the processes of investigation that were entered into, the passing upon modes and materials, the acceptance of some and the rejection of others, etc., etc. I can only refer to these details, which are accessible to members of the Society who take an interest in the matter, in my

official reports to the Department of Parks during the progress of the work, and also in the later publications in the *Journal of the Franklin Institute.*

There are some other points in the discussion which I can only notice briefly.

Differences of opinion were expressed as between heavy and light rolling. From my experience I must give my vote for the heavy roller as I regard the use of such a roller as among the secrets of good road-making. The heavy roller used in Central Park weighed, when loaded to its maximum capacity (with gravel in separate compartments), about 12 tons. The use of this, after trial of lighter ones, made clearly the best roads. This was demonstrated on one section of road in particular, which was carefully observed and on which the wearing surface remained intact much longer than it did on a similar surface not so thoroughly treated. At the same time it may be expedient, in some cases, with fresh materials to use at first a light roller. I do not dispute the evidence of others that light rollers may produce good results by long-continued use.

As regards the practicability of compacting broken stone so as to produce a desirable surface by mere heavy rolling, I cite the following experiment: I was desirous to prove the correctness, or otherwise, of Macadam's theory that clean broken stone could be made to properly consolidate by such rolling.

The result was, after much persistence with the heavy roller, that the surface stones, which were of a fair hard quality, of Macadam size, were rounded in form, and a few crushed by the excessive attrition, and no binding or compacting effect was produced; the rolling was continued until it was apparent that the mass of stones was being compressed into the earth below.

Therefore, it was concluded that Macadam was in error, and that no proper road surface can be formed by the process, in the use of broken stones alone. An intermixture of some foreign material is indispensable. It may be that Macadam succeeded by the use of a softer, inferior quality of stone in crushing a sufficient portion on top to form a binding material of some value, but it is doubtful if a respectable road could be made in this way until after it had been turned over to travel to slowly and uncomfortably perfect it. Such a practice is sometimes tolerated, but I agree with Mr. Brush that it is unwise, and that it is

in no way desirable to force the public to become road-makers. The French practice is not tenacious about the cleanliness of broken stones in road-making, but admits a profuse intermixture of incongruous materials.

As to the exclusive use of Macadam stone in mass for road purposes I protest, as it has always appeared to me to be both unscientific and poor economy; the more modern road, consisting of a foundation bed of larger and cheaper stones, which is to remain as a permanency, and a lighter body of surface material to receive the wear and to be renewed as occasion requires, is far preferable.

I note further a singular difference of opinion as to the length of time a road should be expected to be severely let alone without repairs. It seems to me it is obvious that this must depend entirely upon the nature of the service it is subjected to, with the prior question of the perfection of construction. The surface material wears out and must be renewed. It requires some watchfulness and good judgment to hit upon just the right time to attend to the business. It is idle to attempt to establish any rule about it. The case of each road must be judged by itself, having regard to the patient endurance of the public for shortcomings and culpable neglect. The section of Park road which I have mentioned as having been heavily rolled, maintained its good surface, under moderate travel, for at least three years, and was not then so worn as to require more than trifling repairs; but this cannot be cited as any criterion applicable to general and very variable conditions in the matter of repairs.

The question as to the removal of worn-out material on the surface of roads before making repairs has received some discussion.

Such debris has clearly performed its duty and is fit thereafter only to make mud or dust, and is worse than useless; it is not the kind of stuff suitable for binding material in the renewal of the surface, and the best thing that can be done with it is to scrape it off and consign it to some dumping ground, or, perhaps better, to a compost bed. I know that this is not the general rule of treatment, but for all respectable roads I commend it. I may add that all kinds of limestone I have found by trial are objectionable in forming the wearing surface of roads; it is difficult to combine it with the necessary binding ingredients, and, after a little use, resolves itself into a pasty substance that terminates in defacing carriages and harness, or an equally dis-

agreeable dust. I tried to combine it with a foundation formed of better stone without success, as it separated and flaked up under the action of horses' feet and carriage wheels.

The flushing or puddling with an excess of water is as objectional, in my experience, as the attempt to compact dry materials.

Do we want hydraulic imperviousness, or could we attain it if we did, on a traveled road surface?

As to the proper depth of road materials which has been discussed, the mean depth for the Park roads was 12 to 14 ins., which has given satisfactory results—no breaking up has been known to me. It is a question to be practically determined by circumstances of situation, the kind and accessibility of materials, the character of the travel, soil built upon, etc., and I should say it was to be left to the judgment of the engineer in charge. I desire, most cordially, to adopt Mr. Brush's estimate of the value of Mr. Owen's paper with which he concluded the recent discussion.

Foster Crowell, M. Am. Soc. C. E.—This admirable and timely paper is so comprehensive and so replete with its author's wide experience in the art of road-building that there is scarcely opportunity for any new facts to be brought out in discussing it. But it is at the same time so suggestive in regard to the important part that the engineer should take in the work of transforming the highways of this country into roadways that a few further comments may not be inopportune. The roads which Mr. Owen has built and their economic effect upon the communities which they serve constitute one of the few object lessons in this subject which it is possible for Americans to study without going abroad, and it is not too much to say that it is largely to his effort as the engineer, supported by local appreciation of both the direct and the indirect benefit of good roads which those efforts have fostered and justified, that we have such a valuable source of practical information. The apathy, not to say the ignorance, of the public generally in regard to the earning power of good roads is astounding. There is at present a very important and general awakening to the miserable character of the American highway, which cannot fail to be productive of great good here and there. The fact remains, however, that first-class roads are still regarded as luxuries, or at least as extravagances to be dreaded as likely to increase the burdens of taxation without measurable return. In this connection Mr. Owen's protest

against "makeshift" roads is very valuable and pertinent. The earning power of a railroad or of a turnpike is a distinct function to be reckoned apart from its value as a developer of the wealth productiveness of the region it serves; the earning power of a common road considered in the same light is the sum it saves to the individual users; it follows that in a sparsely settled community it may not pay as an investment to build so completely and expensively as in more favored localities, but it is a matter of demonstration that it is a very poor country indeed that will not be benefited to an extent greater than the outlay by building really good roads; and, moreover, as Mr. Owen has pointed out, the better the road, the less the annual tax for maintenance, which latter in the case of a poor road is often the measure of a much greater capitalization than would provide the best road.

In the case of any contemplated improvement of an existing road, or the opening of a new road, the above consideration is one of the elements of the engineer's problem, and it is very much to be wished that the public may be educated to the knowledge that it is in such ways that the engineer's work will benefit them most and that it does not consist simply in establishing lines and grades or securing good workmanship, important and indispensable as these are.

My own experience in road-building is too limited and too far back to be of much present interest, but it gives me much pleasure to note that the experience of Mr. Owen in regard to the best depth of a Telford pavement confirms the practice with which I had to do, in constructing the drives in Fairmount Park (in Philadelphia). There we began in our ignorance with a depth of 18 ins. of metal, but very soon adopted a theoretical depth of 9 ins., consisting of a 4-in. course laid by hand and hand-napped, a 3-in. course of coarse crushed stone and a 2-in. course of finer stone, each of the latter being rolled with a steam-roller and the whole top-dressed with screenings; the actual thickness of metal to bring the top surface to the established grade was found to be sometimes as much as 10 ins. notwithstanding that the subgrade had been dressed to proper contour and rolled with 2-ton horse-rollers. My subsequent experience and observation of these roads, extending over several years, proved that the wear of the 9-in. pavement under a large volume of light traffic was more satisfactory than that of the 18-in. My impression is that in after years a gravel binder was added.

In regard to the controverted point of heavy *vs.* light rollers, my experience is that the latter produce better results; the object in rolling is not to force the lower course down, but to compact the upper layers; there is a certain relation of unit weight of roller necessary to do this, but it is probable that a 2-ton roller is sufficiently heavy, and the extra cost of operating it should not count in the matter. In construction steam-power could be used with a light roller as with a heavy one; for maintenance steam should not be used.

In regard to grades I venture to differ from Mr. Owen in his assuming that 1% is the ideal grade for roads; in rare cases where the rise is in one direction for long continuous distance, and if a uniform grade of 1% can be secured without undue expense, it is preferable not to exceed it; but where the road is undulating, with frequent reversions of grade, the horse, in my judgment, will do equally well, or even better, with grades of 2%. It is well known that horses as a rule travel better in a slightly hilly country than on a dead level. Obviously the engineering problem can generally be very much modified by the use of a 2% maximum limitation, as against a 1%.

The question of control of roads is likely to be a controverted one for a long while to come; it is really an economical question, but our fellow citizens generally imagine it to be political. Our country is the only one claiming to be civilized that regards this most important duty as a proper matter to be left to the preference or the caprice of a township or a county; it is rather curious that while there is something of a clamor throughout the country for a governmental administration of railroads which are in most respects private property, there is a strongly marked hostility to applying the principle to the common roads which are wholly public property and already in certain important respects under government control.

LATHAM ANDERSON, M. Am. Soc. C. E.—The writer desires to add his quota of praise of the admirable paper by Mr. Owen. It bristles with vital facts, strong common sense and rich experience. Nevertheless, in the recent discussion, the modifications or limitations suggested by Messrs. North and Brush seem to be well taken. Mr. Owen himself emphasizes the danger of making rules that are too arbitrary and sweeping, and also of blindly accepting traditional canons, based upon experience in other countries and climates. But does he not, in some degree, lay himself open to this same charge, as, for instance, on the following points?

He says: "But the proportional area of gravel districts to what may be called earth districts is so small that it has little effect on the *country at large*" (italics by the present writer). What is meant by "the country at large?"

Does it include the rainy eastern half of the Mississippi Valley, the Great Plains, the Rocky Mountain region and the Pacific Slope? Within this continent of ours, respective regions differ from each other in climate and soils more than do New Jersey and England whence most of our different traditional rules have come. Take the Pacific Coast alone. The southern portion is in the desert zone; the northern is as wet and foggy as England herself. Even in the country bounded by the Appalachians, the 100th meridian, the Lakes and the Gulf of Mexico, the aggregate area within which gravel or shale can be obtained at reasonable distances, either from banks or the beds of streams, is so vast as to furnish homes for a first-class nation.

In the discussion, Mr. Owen says: "Repairs cost more on a sprinkled road than on any other." Mr. Owen has doubtless established this fact experimentally in the particular case of the climate of New Jersey and with Macadam made from trap-rock. How about the experience on the noted San Mateo road out of San Francisco, and on the no less famous Washoe Pike across the Sierras? There (if the writer was correctly informed) it was demonstrated that daily sprinkling—not flooding—was essential to the most economical maintenance.

The fact is we live in "all sorts of a country," and current literature, professional and otherwise, is too prone to ignore this fact. Every schoolboy can describe the physical geography of the continent, but apparently the majority of dwellers on our Eastern (Atlantic) frontier fail to realize, in its full force, the relative importance and extent of the different sections. For instance, how few realize that the United States consists of two main divisions—the Mississippi Valley and the Great Mountains, with a comparatively narrow fringe of territory on the Lakes and on the Atlantic and Pacific coasts.

It is needless to say that American engineers of Mr. Owen's wide experience are not amenable to this charge of provincialism. But in our professional papers and discussions attention is, of course, mainly directed to those thickly populated districts in which most engineering work is done. This accounts for the fact that only general mention is usually made of the modifications of these rules of practice de-

manded in rural regions. Consequently the effect which this mode of discussing the road question has upon the rustic mind is to leave the impression that engineering methods therein inculcated are provincial (Eastern) or local, being adapted only to the suburbs of cities or to other wealthy neighborhoods. Thanks to the influence mainly of the American League of Wheelmen, a widespread interest has lately been excited throughout the eastern half of the continent on the subject of country roads. Therefore, a discussion of this phase of the question by our society is opportune, and a dissemination of these professional conclusions throughout the country would at this time be of great benefit.

The object of the writer is not to enter into a general discussion of Mr. Owen's paper, but to refer only to those points applicable to country roads, and especially to those in more sparsely populated districts. It is also desired to restrict the discussion to that rainy, muddy part of our country east of Central Kansas, because first, this embraces about all the region within which the present excited interest in road improvement exists; and second, what would be good practice here would, in many particulars, be quite the reverse in the arid regions of the remaining two-thirds of the country.

First in the order of importance the writer wishes to place the roads stigmatized and denounced by Mr. Owen as "good enough." Mr. North truly says: "The improvement must commence with "good-enough" roads that are as much better than the present style as the skill and money attainable will permit." Now, these wild country roads show the lack of engineering design in every feature, especially in location, surface, drainage, and most of all (in this muddy region especially under consideration) in under-drainage. Given an earth road skillfully located, properly shaped for surface drainage, and with the roadbed thoroughly underdrained with tile, say, to the depth of at least 2 ft., all that is necessary to make this a fairly good country road is to cover a strip in the middle, say, 14 to 16 ft. wide with 6 ins. of gravel or shale. The contrast between such a road and the typical morass through which our farmers flounder in winter is obvious enough.

An ideal country road of this class may be described as follows: in grading, excavate ample ditches, embanking the earth thus obtained so as to raise the subgrade above the surrounding ground (except on hill-

sides). Let the width between the inner edges be not less than 36 ft. Thus, if the middle 16 ft. were graveled, a "mud" road 10 ft. wide would be left on each side. These mud roads afford the best of tracks in dry weather, and save wear of metal on the middle road. The bottoms of the gutters or side ditches should be graded true so that no puddles would form in them.

Provide proper culverts (of logs or planks where other material is too expensive), and, on hillsides, furrows or ditches to intercept flood water from above.

This brings us to the feature to which attention is particularly directed, the under-drainage.

In all clay or tenacious soils, if the roadbed is under-drained with tiles, the road will be rendered more firm during the winter and spring months, and the effect of frost will be reduced to a minimum. It is claimed that, even without metal, such mud roads can be maintained in better condition and at less cost than where under-drainage is not used. Where metal is used, a less depth of it will bear up a given maximum load, thereby repaying a part at least of the cost of the tile. For these reasons, under-drainage of macadamized roads on clay soil is generally recommended by the writer in all but those exceptional cases where tiles are very costly. In most soils and situations, one line of tile under the middle of the road, laid 30 ins. below the natural surface (before embanking the road), will be sufficient. Objection may be urged against this system on the score of first cost. But, from the writer's observation, if the same labor now squandered where the personal service system is in vogue where applied under competent supervision, the roads in our rural districts would be progressively transformed with little additional cost to the community.

Without such skillful supervision, the case is hopeless. It will never be secured until the people are educated to the necessity of putting all such work under the control of well-instructed civil engineers. It is in this direction that our allies, the League of American Wheelmen, with Col. Pope at their head, can do the most efficient service.

W. C. Oastler, Assoc. Am. Soc. C. E.—There is so much in Mr. Owen's interesting and useful paper that is, or ought to be, so entirely outside controversy that I almost wish the few points I desire to notice had been differently treated, because I think they are not

only very far removed from the best practice in road-making, but are apt, unfortunately, to beget and encourage loose and insufficient methods of construction and repair.

Among the important differences of opinion between Mr. Owen and myself are, his practice of grading the earth subway to a surface uniform (in section) with the finished road; his preference for laying the Telford blocks on a loose earth foundation rather than on a consolidated one; the use of clay as packing, and the discarding of the heavy compressing power of the steam-roller (which varies from 400 lbs. to 550 lbs. per linear inch) for a 2-ton horse-roller giving perhaps not more than one-sixth the weight per inch run of the lighter steam-roller named.

I hardly think that Mr. Owen is correct about it being agreed on all sides that the roadbed should be graded to a surface uniform with the finished road, and I know that in several important cities the plan outlined below is preferred and practiced. This less expensive method is to make the surface of the earth subway a right line rather than a curve, and on this flat surface, which should be thoroughly and uniformly consolidated, the Telford foundation is to be laid. If the subway were curved, the Telford stones must be necessarily of the same dimensions; but, by laying them on a flat surface, the curvature of the road can be obtained by placing larger stones on the crown of the road and diminishing their size, and consequently the depth of the road, as the gutters are approached. This plan enables stones of varying sizes to be used in the Telford foundation, decreases the quantity of earth to be excavated and materially lessens the cost of construction as compared with the method of grading the earth to the section of the finished road.

The suggestion that the earth subway, being flattened instead of being an arc of a circle, causes the drainage to be defective or insufficient, is not correct in practice. No earth foundation, either curved or flat, no matter how thoroughly it is compressed, can be rendered waterproof. The principal reason for rolling the earth subway is to obtain as surely as possible an uniformly compressed foundation—a foundation without soft spots in it; so that when the road is built upon it and the traffic comes upon the road, neither the one nor the other shall be sufficient to depress or disturb any part of the structure. It is a

serious error to omit this first precaution, and the omission cannot be too strongly deprecated.

The stone road above the foundation will, if properly rolled, be practically water-tight, and will preserve itself and the foundation against the inroads of water. I do not believe it is worth time or money to make elaborate schemes for under-drainage of broken-stone roads. Lateral drains, honey-combed foundations and other expenses for so-called drainage are wasteful excess and generally can be omitted.

I do not like Mr. Owen's plan of laying the stones on a loose foundation, and the illustration given by that gentleman of scooping out the sand in laying a granite-block pavement is hardly analogous to a Telford foundation, because in the first case the top of the granite block is the wearing surface of the road and must necessarily be an even surface; whereas, on the top of the Telford foundation several inches of broken stone have to be laid, giving abundant opportunity for making level the unevennesses of the top of the large stones of the first layer. I should greatly prefer, and should expect far better results from, first of all, making the earth foundation uniformly solid and then building on this solidity rather than upon the yielding surface of an unconsolidated subway.

With regard to the use of loam or clay in any part of a broken stone road, I am an uncompromising opponent. If clay or loam is placed between the layers of stone of which the road is built, it will sooner or later give way under the pressure from above, the stones will sink down and the road will become prematurely uneven. If clay or loam be used as binding material it will be mud in wet weather and dust in dry weather, to the great disparagement of the road from the traveler's point of view, and will certainly beget undue unevenness and wear and tear, and the consequent increased cost of making good these deficiencies.

I prefer fine gravel or sand as a binding material to anything else, and, no matter what the "binder" is, I think the less used, the cleaner and more durable will be the roadway. Screenings and fine broken stone, particularly when of trap rock, are objectionable because they do not readily bind, and screenings of any description of stone soon grind into dust, which is blown away with the first wind or washed away with the first shower. Moreover, the small stones inter-

mix themselves with the larger stones and keep them asunder. Inasmuch as the object to be attained is to make the road, as nearly as possible, a solid mass of broken stone, it is preferable to use some material, such as gravel or sand, that will not interfere with the stones coming close together, but merely fill up the interstices of the newly rolled road. I would sweep off the surplus "binding" and allow the traffic to come into direct contact with the clean broken stone. A grit of any kind between the wheels of the vehicle and the stones of the roadway destroys the road and wears the wheels. The omission, therefore, of the "top dressing," as it is sometimes named, is honored in the observance.

On the subject of heavy rolling and thorough consolidation I suppose I have some strong views, but as I am commercially interested in the success of steam road rolling, I prefer to say as little as possible on the matter. I have lately formulated, however, half a dozen questions relating to some of the mooted points in Mr. Owen's paper, and asked a number of gentlemen, City Engineers, Commissioners of Public Works, Commissioners of Roads and others, to answer these questions. Twenty-eight of these gentlemen have very kindly responded, and a large amount of extremely useful and interesting information has been obtained. An abstract of the answers is appended hereto, and the fuller information imparted I shall have pleasure in giving to those who may inquire of me.

The answers received from the following gentlemen have been condensed and are printed in the following pages under the question asked; the roman numeral being used to designate each of the individuals, as appears in the following list:

I. Providence, R. I., Samuel M. Gray, M. Am. Soc. C. E.
II. Staten Island, N. Y., W. S. Bacot, M. Am. Soc. C. E.
III. Rochester, N. Y., George W. Aldridge, Pres. Executive Board.
IV. Dubuque, Ia., E. C. Blake, City Engineer.
V. Boston, Mass., W. E. McClintock, M. Am. Soc. C. E.
VI. Paterson, N. J., John T. Hilton, C. E.
VII. Boston, Mass., C. R. Cutler, Acting Supt. of Streets.
VIII. Bridgeport, Conn., B. D. Pierce, Street Commissioner.
IX. Lowell, Mass., Geo. Bowers, City Engineer.
X. Huntingdon, Pa., J. C. Blair.

XI. Providence, R. I., Robert E. Smith, Commr. of Public Works.

XII. Mt. Vernon, N. Y., Fred. S. Odell, Commr. of Public Works.

XIII. Quincy, Mass., W. W. Ewell, Commissioner of Public Works.

XIV. Saratoga, N. Y., Charles L. Pond, Street Commissioner.

XV. Pawtucket, R. I., Loren G. Ladd, Commr. of Highways.

XVI. Keokuk, Ia., W. H. Jones, City Engineer.

XVII. Brooklyn, N. Y., John Y. Culyer, M. Am. Soc. C. E.

XVIII. Medford, Mass., John P. Prichard, Street Commissioner.

XIX. Lynn, Mass., Wallace Bates, Superintendent of Streets.

XX. Wilmington, Del., H. J. Wiley, Sec. Street and Sewer Dept.

XXI. Richmond, Va., Charles E. Ashburner, Jr., Eng. of Roads.

XXII. Chicago, Ill., J. A. Pettigrew, Superintendent Lincoln Park.

XXIII. Stamford, Conn., W. B. Pierce, Borough Engineer.

XXIV. Providence, R. I., John A. Coleman, Ex-Commr. Pub. W'ks.

XXV. Flushing, N. Y., G. A. Roullier, M. Am. Soc. C. E.

XXVI. West Newton, Mass., Albert F. Noyes, M. Am. Soc. C. E., City Engineer.

XXVII. Madison, Wis., McClellan Dodge, City Engineer.

XXVIII. Fall River, Mass., Anthony Thurston, Supt. of Streets.

Question No. 1.

Please state whether you prefer to use a steam-roller or a horse-roller in the construction and repair of broken-stone roads, and why the preference.

Answers.

I. Greatly prefer steam-roller. Much better road can be made at less cost and in less time.

II. Steam-roller. Economy, efficient work, speed, better road, etc.

III. Steam-roller. Labor and time saved, more solid and compact bed, smooth surface and more durable road.

IV. Steam-roller. Packs Macadam and leaves it smooth. Horses tear up street and leave it uneven.

V. Steam-roller. Better work, more durable, etc.

VI. Steam-roller. Consolidates road more compactly and solid than can be done with horses.

VII. Steam-roller. Wherever work is large enough to may it pay. Small patching—horse-rollers.

VIII. Steam-roller. Better work, better consolidation than horse-roller.

IX. Steam-roller. Decided preference for.

X. Steam-roller. Both for new roads and repairing.

XI. Steam-roller. Better work and more economical. Have grades on which horse-roller would not work.
XII. Steam-roller. Action of driving wheels draws stones more closely together, greater weight, compacts better than horse-roller.
XIII. Steam-roller. Firmer and more compact road, difference in appearance and wear apparent to all.
XIV. Steam-roller. Road solidly compacted and fit for use, something impossible with horse-roller.
XV. Steam-roller. Greater weight, compacts more thoroughly and leaves surface better for travel.
XVI. Steam-roller. More economical than horse-roller, and giving a more compact and durable street.
XVII. Steam-roller. Decidedly. More economical, and because results in uniformity and efficiency of work done are in all respects better.
XVIII. Steam-roller. Indispensable.
XIX. Steam-roller. Far more effective. Needs no argument to satisfy any unprejudiced mind that a 15-ton pressure is more effective than a 5-ton pressure.
XX. Steam-roller. More thoroughly compacts.
XXI. Steam-roller. Most decidedly. One week's work with a horse-roller and a steam-roller should satisfy anybody.
XXII. Steam-roller. Cheaper worked and better work.
XXIII. Steam-roller.
XXIV. Steam-roller. Its infinitely greater effectiveness.
XXV. Steam-roller. Interlocking more compactly—voids reduced to a minimum and less binding required. Roadway approaches more nearly a solid mass of stone.
XXVI. First use ring-roller, 2-ton, and then steam-roller.
XXVII. Much prefer steam-roller.
XXVIII. Steam-roller. Handsome, durable road.

RECAPITULATION.

Answers received, 28.

Prefer steam-roller to horse-roller	27
Two-ton "ring-roller" first, then thoroughly consolidate with steam-roller	1

Question No. 2.

Are steam-rolled roads pleasanter and cleaner for travel and more durable than roads not so rolled?

Answers.

I. Not only much pleasanter and cleaner, but more durable, and, I think, more promotive of sanitary conditions.
II. Decidedly; and more durable, less muddy in wet weather and less dusty in dry; therefore, cleaner.
III. Yes. There is no pleasanter road than a well-rolled Macadam.
IV. Streets that are rolled by steam-roller are more easily swept. A road not so rolled will never be so pleasant for driving.
V. Steam-roller requires far less binding than horse-roller. All binding a necessary evil. Less, the better and cleaner.
VI. Decidedly so.
VII. No answer.
VIII. Much pleasanter and cleaner, and last longer.
IX. Good road can be made so much quicker and easier with steam-roller; the result is apt to be a better road.
X. Yes. Greatly.
XI. More compact and evenly rolled, and more durable.
XII. Depends on traffic. Have made roads for light travel with horse-roller quite as clean and pleasant as any constructed with steam-roller.
XIII. They certainly are.
XIV. Far pleasanter and cleaner, and much, very much, more durable.
XV. They are by far.
XVI. Give us better service, and require less repairs.
XVII. Yes, certainly.
XVIII. Pleasanter and cleaner and more durable, and wearing surface lasts a great while longer.
XIX. Most decidely so.
XX. Yes.
XXI. Smoother, pleasanter, cleaner, more compact.
XXII. Yes. Firmer and more compacted, less settlement. Mud and dust can be reduced to a minimum.
XXIII. No answer.
XXIV. They are, decidedly.
XXV. Prefers steam-rolled roads.
XXVI. No question about well-rolled roads being more durable and pleasant.
XXVII. Yes.
XXVIII. They are.

Recapitulation.

Answers received, 26.

Steam-rolled roads are pleasanter for travel and are cleaner and more durable....................................	25
Depends on traffic. Have made roads for light travel with horse-roller quite as clean and pleasant as any made with steam-roller..	1

Question No. 3.

What "binding material" do you use or prefer? Any particulars of your methods of constructing and repairing broken-stone roads will be greatly esteemed.

Answers.

I. Fine broken stone or dust from crusher. As little binding as possible.
II. Gravel. Sometimes admit hardpan sparsely. No faith in rock dust or screenings. Gravel gives best results.
III. Gravel, neither too fine nor too coarse. Slight mixture of clay.
IV. Quarry screenings.
V. Screenings, same kind as stone used for road.
VI. Sand in preference to any other material.
VII. Fine screenings.
VIII. Gravel sand the best binder.
IX. Fine screenings and little of that.
X. Small limestone, or a peculiar gravel we have here.
XI. Fine screenings.
XII. Screenings from the road metal. Good sharp gravel with small proportion of sand is good.
XIII. Good clean sharp gravel.
XIV. Small broken stone.
XV. Fine stone from crusher.
XVI. Gravel.
XVII. Anything almost rather than clay.
XVIII. Stone screenings from crusher.
XIX. A common blue gravel containing 20 to 30% clay. Smallest amount possible.
XX. Screenings from stone.
XXI. Fine gravel and coarse sand. When these cannot be obtained, then screenings.
XXII. With granite surface we use loamy gravel. With limestone we use screenings from the limestone.
XXIII. Screenings, dust, etc. Cleaner than clay.
XXIV. Stone screenings, and than a layer of sand.
XXV. Coarse, clean sand, with a small amount of coarse screenings. Earth foundation heavily rolled.
XXVI. One-fourth to ½-in. clay and then screenings. Little as possible.
XXVII. Screenings. Limestone.
XXVIII. Screenings.

Recapitulation.

Answers received, 28.

Screenings from the broken stone being used, or small stones	17
Gravel and sand, or gravel or sand	8
Peculiar local gravel, 20 to 30% of clay in it	1
Anything, almost, rather than clay	1
Small quantity of clay and screenings rolled	1

Question No. 4.

What is your opinion of clay or hard-pan as a binding material for broken stone roads ?

Answers.

I. Never used it.
II. Good, if discreetly used.
III. In limited quantities it makes a good binder.
IV. Have not used it as a binder.
V. I should not use clay in any part of a road.
VI. I never use it if I can get anything else.
VII. Does not work as well as fine stone.
VIII. No good ! More of a detriment.
IX. I would not use it.
X. Good.
XI. Clay not good in any way.
XII. I avoid loam and clay.
XIII. I am not a believer in this kind of material.
XIV. I do not like it at all. It keeps working out and covers the surface with mud.
XV. Never used it, but should venture that it would not be so durable as fine stone.
XVI. Experimented with clay and earth. Find they require more cleaning than gravel. Gravel worth additional cost.
XVII. Clay is a material of last resort.
XVIII. I use screened hard-pan on steep grades, with great care not to get too much.
XIX. Gravel contains a portion of clay, as being cleaner than all clay.
XX. Do not consider it durable because it soon works in and allows the stone to come on top.
XXI. Makes a "nice-looking" road for a short time, then mud and dust according to season of year.
XXII. Would not use it if gravel could be obtained.
XXIII. Very good, if you don't get on too much to make mud.
XXIV. We do not believe in it as it makes mud in wet weather.
XXV. Have used clay in small quantities, but the roads have proved more dusty or muddy and have shown a tendency to rut more readily in shaded spots.
XXVI. Clay gives good results when used with certain stone.
XXVII. Have not used it and would not care to.
XXVIII. It would be the last thing I would use.

Recapitulation.

Answers received, 28.

Never used clay	3
In limited quantity, if discreetly used	6
"Would not use clay." "More of a detriment." "Nice-looking road for a time, then mud and dust." "No good." "Tendency to rut roads." "Material of last resort." "Don't believe in it," etc., etc	19

QUESTION No. 5.

Do you use the "picks" in the roller wheels for breaking up old roads before remetaling? And if so, with what success, economically and otherwise?

In repairing roads is it preferable to lay the new metal on the hard old road, or to loosen the old surface with the picks and then add what stone may be needed?

ANSWERS.

I. Used picks with great success. Very essential to break up hard road surface before laying new metal.

II. Used steam-roller in repairing, Find economy in steam picking and roller repairs. If thick layer imposed, sometimes dispense with picks. For thin application always "pick up."

III. Most economical. Not one-third that of hand picking. Loosen the old surface with pick, and then add and roll in the new metal.

IV. By all means have the old road well picked over; then put on the new metal.

V. If road worn down 3 to 5 ins., don't pick up. In case less than three I pick up old surface. Roller picking far less costly in hard roads.

VI. Prefer to use picks. It is preferable to loosen the old surface when about to add new stone.

VII. Always use picks—very economical. I consider it always preferable to loosen old surface so as to make a bond.

VIII. Seldom use picks. Road built of "trap." Picks come in handy on soft stone roads. They are necessary in rebuilding roads.

IX. Used picks with profit. We have good success in thoroughly cleaning old roads and then applying a thin layer and thoroughly rolling with steam-roller.

X. Yes. Loosen old surface.

XI. Used picks with success and economy and prefer to cover surface with picks and then add the needed stone.

XII. Am of opinion that the time spent in breaking up old surface with picks is mostly wasted, and that equally good results are obtained by spreading the new metal on surface and rolling it.

XIII. Always use picks before putting on new material. Does good work economically. If new material is laid on hard old road, it wears faster, etc.

XIV. Use picks with success and economy. Will do the work of 50 men. If metal were laid on the old hard road with an unloosened surface, I should consider it wasted.

XV. Always used picks. Always loosen surface.

XVI. Used with success. Always pick up the surface in repairs, giving the broken stone a chance to compact.

XVII. Most effective and economical. To an engineer deprived of experience up to date of this boon, to witness the process would be a liberal education. General loosening of covering facilitates subsequent work.

XVIII. Use picks with success and economy. It is not a good plan to spread new metal on hard roads. Pick up surface for bond.

XIX. Use picks with complete success. Am very decided in my opinion as to the desirability of loosening the surface before applying new material. A great deal better result is obtained.

XX. Use picks with marked success. It is undoubtedly preferable to loosen the old surface with the roller picks and then add the new stone.

XXI. Very satisfactory. Always pick up surface and get a better bond.

XXII. Always use picks. Road hard as rock, but succumbed to roller with one passage. Have had no trouble in repairing with 2-in. metal without picking up. Less than 2-in. would crush too much.

XXIII. Saves cost considerably. Prefer to pick up old surface, otherwise the junction of old and new roads wears badly and soon ruts.

XXIV. Always used picks. Far more economical than by hand. Preferable to loosen old surface with picks. The new stone should be incorporated with the old.

XXV. Yes; at less than one-third the cost of hand picking. On a clay-bound road, picking not a necessity. On roads constructed as I have previously mentioned, picking up the old surface is imperative.

XXVI. Use picks successfully.

XXVII. Use picks successfully.

XXVIII. Use picks with success and economy, and loosen old surface.

Recapitulation.

Answers received, 28.

1. Used picks in steam-roller with success and economy	26
Time using picks mostly wasted	1
Seldom used picks, "handy on soft roads." Necessary in building new roads	1
2. It is preferable to loosen old roads before putting on new metal	23
If thick layer of stone added, not necessary to pick up. Pick up if thin layer, better bond	4
Time mostly wasted. Put metal on hard road	1

QUESTION No. 6.

What trouble, if any, have you had with the steam-roller in breaking water or gas mains or sewers? And have you found it necessary to abandon the use of the roller because of any breakage to mains, etc., it may have caused?

ANSWERS.

I. Used roller to upwards of 20 tons weight. Never broke water or gas mains or sewers. Never abandoned roller on any account whatever, etc., etc.
II. No trouble of any account.
III. None. No.
IV. No trouble.
V. No trouble.
VI. None. I have not.
VII. No trouble.
VIII. Have had no trouble.
IX. No trouble.
X. None.
XI. No trouble.
XII. Stoneware pipe culverts near surface have been broken; otherwise, no trouble.
XIII. No trouble.
XIV. None worth speaking of.
XV. A few strained joints of gas pipes near surface and when newly laid. Instead of abandoning the roller, have just bought a second.
XVI. No trouble except when mains less than 18 ins. below surface. Had to abandon roller where mains were only a few inches under ground.
XVII. Had no trouble.
XVIII. No trouble.
XIX. Very little difficulty. No trouble when pipes and sewers were the proper depth.
XX. Some trouble in the small gas mains. They were not deep enough. Not abandoned roller.
XXI. Very little trouble, and this because of badly constructed wood culverts. I would strengthen every culvert and bridge before I would abandon the steam-roller.
XXII. No trouble.
XXIII. No damage, except a few manhole covers broken.
XXIV. No trouble.
XXV. No trouble whatever.
XXVI. No trouble.
XXVII. No trouble.
XXVIII. No trouble.

RECAPITULATION.

Answers received, 28.

No trouble whatever	22
Very slight, and these due to mains being laid a few inches under surface	6
Abandoned roller	None.

P. Callanan, Esq.—The admirable paper of James Owen, M. Am. Soc. C. E., is worthy the careful study of all interested in the construction of good roads. It is highly instructive and gives in a clear way the results of a long and valuable experience in road-building.

There are several important points treated in the paper on which the experience of the writer does not coincide with that of Mr. Owen, among which are the relative value of materials; the relative value and practicability of Telford and Macadam, and the manner of rolling.

As to Material.—Concerning road material Mr. Owen says : "Leaving the drainage question, the next subject is that of material, and here the field widens and opens. It may be proper to state at once that in a sense the writer's experience in proper road materials is to some extent limited. Having by good fortune at his command the best possible material for road purposes he has felt reluctant and is reluctant to venture into the unknown in haste and repent at leisure." He speaks of his limited experience in road material and of his reluctance to venture into the unknown, and in the same sentence declares he has at his command the best possible material for road purposes. He claims that trap is the best material and that limestone is only economical or desirable in localities in which it occurs. It is a fact that there are many grades of limestone of greatly varying composition. If there are any grades of limestone that are suitable for road purposes they should be excepted in the sweeping and general condemnation of all limestone by Mr. Owen.

There are many portions of New York State, remote from any deposit of trap, in which limestone abounds and can be used to macadamize highways most economically and durably. It would be detrimental to the interest of taxpayers and the public in such localities, to have the minds of those in charge of road affairs prejudiced against one of the very best of road materials, and which may be found close at hand. The utterances of so eminent an authority on roads as Mr. Owen carry great weight, and it surely is not his purpose to underestimate intentionally the value of any road metal. His condemnation of limestone is probably due to the fact that he has had to do with a grade in which silica and magnesia abound and which readily disintegrates by the action of traffic.

The writer has in mind the product of a hard limestone quarry of very different quality from that just described. As evidences of its

hardness and toughness it is proper to mention that 75% dynamite is absolutely required to rend this stone, when ordinarily from 30 to 50% dynamite is used in quarries. Another point in proof is the fact that the Troy Steel and Iron Company, after finding that this limestone analyzed perfectly for their use, found it impossible to readily flux it. A better proof of the fitness of this limestone to rank with the very best road material is the instances where it has been put to a practical test. It has been used to macadamize streets in large villages. It was used to macadamize the main street of a large manufacturing village, and is there subjected to severe and almost perpetual traffic. One concern (of which there are many) carted 25 000 tons of merchandise over this street last year. It is a 6-in. Macadam, built in the summer of 1891. It came out of the following winter without a "scratch." The people of the village had predicted all sorts of disasters to befall their Macadam when the frost should withdraw, and their satisfaction was complete when they saw it not a bit disturbed or injured by the action of the frost, and straightway contracted for another piece of the same kind of street. Now, here we have a 6-in. Macadam streetway made of limestone easily withstanding immense traffic nearing the end of its second year—no repairs, only ordinary care in cleaning—without rut, its contour perfectly preserved, the whole roadway a solid, smooth-surfaced and unyielding mass, as any reliable citizen of the town will gladly testify. "Look on this picture, and on this." Mr. Owen says: "The success of hard limestone in rainy localities "—mark the words —" is due, in the writer's opinion, to its comparison, not with harder and better rock, but with the aboriginal mud." This seems to be straining a point in the effort to belittle the value of limestone. We submit the facts concerning the road above described, which can easily be verified, for they are patent and open as the day, against an opinion. Here a condition confronts a theory.

Speaking of comparisons, the limestone road in question is worthy to be compared with any stone road anywhere of trap or other rock, for no stone road can be better than a road which is hard, smooth and durable.

Mr. Owen charges limestone roads with being dusty in dry weather and muddy in wet. Is that not equally true of all stone roads left to themselves? The writer can point out a road upon which trap has been freely applied, without rolling, and which for depth and nasti-

ness of mud and dust in wet and dry times surpasses anything of the kind he ever saw on any other stone road.

Anyone hoping to find a stone road that will not receive deposits of dirt, or not powder more or less under wear, that has a self-cleansing, self-rejecting surface, had better hasten to rid himself of that illusion. Inexpensive machinery is made that will rapidly and effectually remove all dirt and will amply repay in comfort and durability of the road. Even asphalt and block pavements, which of themselves contribute nothing to the supply of dust, must be sprinkled daily and swept often to preserve a clean condition. Mr. Owen claims that repairs cost more on a sprinkled than on an unsprinkled road. That we believe to be true, provided the road is not cleaned at proper intervals; but that if the accumulations are removed at such times, that a reasonable amount of sprinkling is not detrimental. It is claimed by asphalt companies that their pavement wears out much sooner when it is continually sprinkled without being cleaned.

As to the Relative Value and Practicability of Telford and Macadam.— First, the much greater cost of Telford must make us pause to consider well whether or no Macadam can be so constructed as to furnish a suitable roadway. Telford is demanded only where the soil is wet, unstable and treacherous. In such cases, unless the stone is near at hand to supply the Telford foundation, skillful workmanship in laying the Macadam would give the most satisfactory results. Superior drainage, the introduction of easily obtainable soil upon which frost has little effect, skillful manner of rolling and applying the different courses of broken stone, may be substituted for the more costly Telford. Mr. Owen's belief that in a cold climate Macadam is practically nowhere compared with Telford is not confirmed by results in cases of several 6-in. Macadam roads in the latitude of Albany, N. Y. These roads were carefully constructed with the view of withstanding the frost's action, and are not disappointing their builder. In most localities the expensive nature of Telford takes it out of the question for building country roads. Moreover, it is not essential to the construction of good roads in most localities.

As to the Manner of Rolling, Depth and Size of Stone.—It has been the writer's practice in building village streetways to grade the roadbed to a surface uniform with the finished surface, securing a good lateral drainage, then rolling the roadbed thoroughly with a 15-ton steam-

roller. The heavy rolling disclosing the weak places which are filled with suitable material and brought up to the required grade. If it is to be a 6-in. road, enough stone is applied in one course, so that after the steam-roller has done its work there is 6 ins. of consolidated stone.

In order to prevent the stone from "bunching" and cause the surface to show in waves after some wear, as they will do when dumped directly on the roadbed and worked over with hooks, it is dumped on a platform of plank and shoveled to an even depth in its place.

The shrinking under steam-rolling has ordinarily been 40 to 50%. Could a two-horse-roller produce a like effect with any number of times rolling? And is it not important to have as much shrinking done at time of construction as possible?

Shrinking means that the pieces of stone are being driven closer together by the immense pressure upon them; that it is the process of solidifying, assorting, knitting, interlocking, making the whole mass as much like a unit as possible, and all the better prepared to withstand usage. I agree with Mr. North's view of the manner of rolling. In cases where the natural soil is not so favorable and it was deemed well to put down 8-in. Macadam, it has been found best to apply the broken stone in two courses, each properly compacted with the steam-roller and finished with a shallow binder of screenings.

The idea of a rut is at all times hateful, and all travel should be denied until the rolling is completed. The point of fracture and quality of stone used should be such that the pieces will bind and hold together in wet or dry weather, with the rolling thoroughly done. This is the history of the road built in the manufacturing village hereinbefore mentioned. There never was a rut in this road, even from the very first. A rut is a sign of weakness, insufficient rolling, or that the stone lacks the compacting quality. Mr. Owen says, "A rut on the surface wears out," but the general experience is that it wears in. They would seem to have no proper place in a new road, at least.

Another important result of heavy steam-rolling is that the Macadam is rendered more nearly impervious to water, the stone and screening and packing being so compact as to almost completely prevent percolation of water through the Macadam, so that with good lateral drainage and proper amount of crowning there will be a minimum of moisture in the stone and in the earth under it, thereby lessening the injury by the withdrawal of the frost.

In this way a 6-in. road will withstand as much heavy traffic as a 12-in. road. As only the surface receives the wear, any natural soil that can be made to furnish a stable base for the Macadam, the Macadam will protect, and bears the same relation to it as does the felloe to the tire.

The size of stone that makes the best wearing surface would seem to be the largest size that still has the power to assort, bind and unite closely, to present a smooth, full, wearing surface, following the principle that a large stone is stronger than a smaller one. In the streetway alluded to in this article, the writer used stone varying in size from 1 in. to 2½ ins., with admirable results. Stone must, of necessity, vary in size, and it would seem wise to select the largest size that will still answer the essential requirements of surface stone.

EDWIN MITCHELL, Assoc. M. Am. Soc. C. E.—The Cumberland Valley, lying between the easternmost two ranges of the Blue Ridge Mountains, extending through Pennsylvania and Maryland from the Susquehanna River to the Potomac, affords a number of examples of turnpikes which have not a heavy foundation, but nevertheless show little damage from settlement, most of the repairs being due to wearing away of the surface. The Trenton limestone abounds in all parts of the valley, joining at the mountains the Hudson River slate and Utica shale. The soil is a heavy red clay which in the "dirt roads," in bad weather, frequently makes them impassable. All of the public roads are simply graded clay roads, the turnpikes being owned by stock companies. Notwithstanding the bad experiences winter after winter, propositions to issue county bonds for road improvements have been defeated by overwhelming majorities. It seems a more difficult matter to educate popular sentiment than it will ever prove to raise the necessary money. Consequently most of the highways are poor specimens of the "good-enough roads."

Three of the turnpikes across the valley are portions of the highways built in the first decade of the century, connecting Baltimore or Philadelphia on the east, and Pittsburgh or Wheeling on the west. These roads are admirably located with good, wide roadbeds.

The Chambersburg Turnpike, a link of 15 miles in the road between Baltimore and Pittsburgh, built in 1810 through the flat portions of the valley with very little grading, cost $3 000 per mile. Some turnpikes, including both hill and valley construction, cost as

much as $8,000 per mile. These turnpikes, now having lost most of their old-time heavy traffic, receive only such repairs as are absolutely necessary. During the past few years the average yearly expenditure on the Chambersburg Turnpike, above referred to, has been $132 per mile, which represents a fair average for other roads of the same class. New stone is put on only the central 12 ft. of the turnpike, and is spread loosely to a depth of from 4 to 6 ins. The average amount used each year is about 100 perches of 25 cub. ft. per mile, which is sufficient to renew a width of 12 ft. one-tenth of a mile. Limestone is the only stone used, owing to its abundance and the cheapness with which it can be procured. Limestone can be quarried for 30 cents a perch and knapped by hand for the same amount. Crusher-broken stone costs on the turnpike from 80 cents to $1 20, according to the distance it is hauled. The cost of granite would be at least twice as much. The fresh stone is not rolled, but is left to be packed by the traffic. On the most traveled portions of the road, this requires about two months.

I am familiar with but one turnpike that has been constructed in the past few years, the Downsville Turnpike. This has been macadamized for a width of 15 ft. to a depth of 8 ins. The lower layers are of stone from 3 to 5 ins. in diameter, the upper stones are from 2 to 3 ins. The method of building was the same as in the old turnpikes, the stone being thrown down loosely and left to be packed by the passage of vehicles. This is not to be commended as a practice, but is cheap, and in this case has produced an excellent result after severe tribulations and shakings and joltings of the users during the first few months. The older parts of this road, built about five years ago, have had nothing expended on them for repairs and are still in good condition. The cost of building has been from $1 700 to $2 000 per mile. A contract for a portion was let at $1 700 per mile, but before much was accomplished, the contractor threw up the work.

The public roads of Washington County, Md., have only an average of $20 per mile spent on them each year (most of this is wasted) and their condition is execrable. The same may be said of the roads of other parts of the valley. Franklin County, Pa., last year spent $60 000 on road repairs, but all the benefit received was washed away long ago.

The farmers living on the turnpikes and paying 1 cent toll per mile per horse are much more than repaid by the decreased cost of trans-

portation. When all of our country population can be taught to see this, the difficulty of raising money for our roads will be overcome and we can pass beyond the "good-enough" stage in road-building.

Samuel L. Cooper, M. Am. Soc. C. E.—Mr. Owen advocates Telford roads, and uses light rollers and some loam as a binder. He makes good roads on this plan at reasonable cost.

Others, particularly Mr. North, advocate Macadam roads, use steam rollers, and no loam. There are plenty of examples of these roads that are entirely successful.

Telford roads can be more successfully made with light rollers than Macadam roads.

The Telford roads, put together with loam and light rolling, stand because the water, that will surely find its way through the metal, is drained away through the Telford.

The Macadam roads, put together in the same way, will go to pieces, because subdrainage is not provided.

The successful Macadam road-builder must omit the loam and seek the utmost consolidation by steam-rolling. He must make a water-tight road, and a more perfect surface to shed the rain. It would seem to be plain, that a Telford road, having a subgrade rolled to ultimate resistance, and the metal consolidated by a heavy roller, without any loam, would be a more durable and perfect road than a Telford road on Mr. Owen's plan.

I would prefer an 8-in. Telford road made on Mr. Owen's plan to an 8-in. Macadam road made on the same plan, namely, with some loam and with light rollers. But I would greatly prefer the 8-in. Telford road made with no loam and heavy roller. It will usually be found that the last will cost little or no more, particularly if a good local stone can be obtained for the Telford.

So far as repairs are concerned, I believe that Mr. Owen's method will do far better on a Telford road than on a Macadam road; but even if we could make roads that would wear uniformly, which I doubt, there are certain defects that are sure to appear in most roads, due to frost and storm, and not to faulty construction, which should receive immediate attention. I believe that there is economy in repairing in the fall and spring, and in prolonged spells of drought and wetness.

There are more chances of failure in Macadam roads than in Telford

roads, because the latter are more difficult to make and require more attention to maintain.

It is observed in the discussions on this paper, that while the contention begun by the fathers of good roads as to the relative merits of Telford and Macadam pavements is not yet settled, yet the majority strongly advocate the Telford construction; and, also, that of the advocates of both systems, those who prefer the heavy roller are in a large majority, Mr. Owen himself being the most conspicuous among the minority.

Personally, I prefer the Telford road, made without loam, and with a steam-roller used with judgment, as the most economical and perfect road.

E. E. RUSSELL TRATMAN, Assoc. M. Am. Soc. C. E.—As to machine-broken and hand-broken stone, I know of a district in England where the stone has been first roughly broken by machine, then hauled to the roads and piled, and there broken by hand to the finished size. The objection found to the machine-broken stone was the irregularity in size and shape, and the presence of long narrow pieces which prevented proper binding. The preliminary machine work was probably to save the time that would have been required in breaking down the large blocks by hand. This was on main country roads, with heavy traffic and near large towns. Steam-rollers were not used, but it was proposed to employ them in the future. The English practice is, in general, to give constant attention to the road, in much the same way as the maintenance of railway track is carried on, for road maintenance is not merely the laying of broken stone. There are regular gangs of men on the road sections to attend to general maintenance, filling up incipient ruts and depressions, scraping and cleaning, trimming grass and hedges, clearing gutters and ditches, breaking stone, etc. In the spring and autumn, when more extensive repairs are to be made, sections of road remetaled, ditches and drains and culverts to be attended to, etc., additional men are employed. The country roads are divided into two classes, main roads and district roads, and all road work is under the supervision of county and district engineers, who have to keep records of expenses, materials used, etc., and to report periodically to the public authorities. For removing mud the wheeled scraper, operated by hand, is largely used. The form is shown in the rough sketch, Fig. 1, and as the length of the scraper is made up of a

number of separate pieces, of ┌ shape, all hinged together, the edge accommodates itself to any slight depressions, and does not tend to injure the surface.

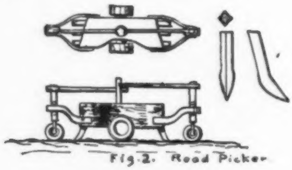

Fig. 2. Road Picker

Fig. 1. Mud Scraper.

Reference has been made to picking up the old road surface, before applying fresh stone, by means of picks on the wheels of a steam road-roller. In the autumn of 1890 I observed the remacadamizing of the roadway of the Thames Embankment, in London. For breaking up the surface a device was used of the form roughly sketched in Fig. 2, which was hauled along the roadway by a traction engine or road-roller having a pair of carrying wheels instead of rollers under the smokebox. It is a small, heavy trolley, consisting of a cast-iron block about 2 ft. long, mounted on little wheels and fitted at each end with three knives or "picks" which cut three parallel furrows, the depth being regulated by raising or lowering the block by means of screws on the vertical shafts of the end wheels. The screws are turned by wooden levers, the ends of which are lashed to a center post when not in use. The use of picks at each end is to avoid having to turn the trolley. A gang of men with picks, spades and rakes spread and leveled the broken surface. The new Macadam was then put on and rolled dry by steam-rollers. Then a binding of dark yellow gravel was spread, watered and rolled until a wave of the water and gravel flowed in front of the roller. Another layer of gravel was then spread and rolled to the finished surface. The old surface was well watered before being picked. The new stone was about 2½ to 3 ins. in size, evidently machine-broken, judging by the number of long, thin pieces. Three-wheeled carts were used for hauling the broken stone and gravel, and in hauling gravel over the new Macadam they were not turned round when empty, but the horse was attached to the rear end.

HERBERT M. WILSON, M. Am. Soc. C. E.—It may be of interest to add a few words to this discussion, showing the method employed in India for constructing and maintaining roads of the character described in Mr. Owen's paper. I am not a practical road-builder, and therefore all that I can say on the subject refers merely to personal observation of the methods used on such roads.

Throughout India there is a system of public roads divided into four classes; first, the main or military roads, which are, perhaps, 40 ft. in width and macadamized from curb to curb; the second class, of the same width, 16 ft. of which is macadamized; then the third class, perhaps 20 ft. wide, which are macadamized for a width of 8 ft.; and lastly, the farm roads which are not macadamized at all. These roads have been built without the aid of any machinery other than crude stone rollers. They are built on a carefully prepared surface, generally well aligned and graded by engineers, and the rolling is done by rollers pulled by men or bullocks, and weighing 2 or 3 tons each.

The stone employed generally throughout Northern India for road metaling is a natural hydraulic limestone, called "Kunkar," a stone which I should judge to be much superior to that referred to by Mr. Callahan. The limestone which Mr. Callahan referred to, is, I believe, very much superior to the ordinary limestone of the country. In Southern and Central India trap rock is chiefly used for road metaling. No stone breakers or crushers are used, and the stone is always broken by hand in small pieces of about 1½ to 2 ins. in diameter.

So much for the building of the road and the use of light rollers. The roads of India are from 30 to 60 years old, yet they are among the best roads that I have ever observed. The surface is always good; there are very few bad places on these roads and they are kept in excellent repair. This, however, I do not think is to be accredited necessarily to the method of making or rolling the road, but to the patience with which the Indian laborer attends to the needed repairs. These repairs are being made constantly and at all times. Along the roadsides there are always kept piles of stone, broken or ready to be broken, and when the laborers are not busily engaged in repairing small patches of road which have deteriorated, they are seen sitting on the piles of stone breaking them up with hammers. The patient manner in which they repair the roads doubtless has much to do with their excellent condition.

WILLIAM S. BACOT, M. Am. Soc. C. E.—I have read Mr. Owen's paper with a great deal of interest, and there are many things in it which have struck me as being particularly good ; especially the high ground which Mr. Owen takes in regard to what the general character of road-making should be. He seems to deprecate particularly the practice of making roads which are simply "good enough," and, in fact, of inferior construction generally.

These are some points about Mr. Owen's paper that I would take exception to, because they differ so materially from my own practice that I do not feel as if I could endorse them. Mr. Owen does not seem to be in favor of the use of the steam-roller in any case, but in my work I do not see how we could get along without them. We have had in use no less than seven steam-rollers at different times, varying in weight from 10 to 20 tons, and if we were obliged to build roads without the use of these rollers we would have a lot of stone mixed up with mud and dirt, as we have found often to be the case when we were not careful to roll the road with the steam-rollers. Mr. Owen alludes (Vol. XXVII, p. 618) to an act of the Legislature of the State of New York, and in an analogous fashion accuses the people of Staten Island of being a little bilious. I am inclined to think they were when they allowed their member of Assembly to have a bill of that kind passed ; in one particular, if none other. The law provides very specifically the manner in which the road should be built. It restricts the packing material to one thing, that is, rock dust or screenings. You cannot make a good road, in my estimation, from rock dust and screenings alone. It is impossible to make such a road without a steam-roller. And, in addition to that, you have got to use the wet method of making roads—you must have water. Of course, the finer the screenings are, the more nearly it approximates to sand, the quicker it will bind and the more solid your road becomes.

The only comment I have to make on the practice which we have followed, to a large extent, is this, that the road should be thoroughly saturated with water at the start. For that reason, on account of such excessive use of water the earth roadbed must be very compactly rolled beforehand, and therefore the steam-roller is indispensable in that case. Latterly we have used gravel, sand and other materials, and even clay, and I have found that the results are much better, not only in the first construction of the road, but in the subsequent wear of it,

particularly in dry weather. The surface of a road built of nothing but rock dust as a binder breaks in the first dry spell, and you are compelled to water it, not only village roads, but the others, for the sake of holding it together. In wet weather they are inclined to be muddy. The use of a little clay is not detrimental, but I must insist that the clay be used very moderately. I would say that Mr. Owen's limit as to the depth of it was more correct in the ½ in. than as to the ¾ in., it should never be over ½ in.

After all, gravel seems to be the best thing for binding roads. I have found nothing as good. The silica in the sand is apt to grind up in traffic and it soon becomes muddy, just as screenings will.

In conclusion, the only thing I wish to lay particular stress upon is in regard to comparative merits of the Telford and Macadam roads. The one advantage I find in the use of the steam-roller is that it produces a Macadam road of such superior character that it takes the place of the more expensive Telford construction. An 8-in. road in which gravel is used, or any good binding material, I find to be just as good as a Telford road, and whether there could be any discrimination made in favor of the Telford, I have so far failed to discover. In wet soil it is necessary to have a Telford and particularly on flat grades. The point I wish to make is that without the steam-roller we could not get such good results out of the 8-in. roads; therefore, I claim there is a distinct advantage in employing a steam-roller. In the Telford roads you have a solid foundation underneath, and the necessity for the roller is not so apparent, and I can therefore understand why Mr. Owen is in favor of the Telford roads. I am sure that any one who looks over a newly finished Telford road will find it true that the traffic does little to destroy the surface courses overlying the Telford bottom. In the Macadam road it is quite different; if you do not roll the bottom and roll the first and second layers, the road is almost sure to rut. I have found that to be the case where the contractor has not observed this rule, and perhaps has introduced a little too much of the binding material in addition. When the traffic rolls over the road it ruts, and there is a great deal of difficulty in straightening out the ruts. The only way to cure the trouble is to put a little more stone on the road to even up the surface.

Oscar Saabye, M. Am. Soc. C. E.—I had some years ago a few years of experience in road-making in Denmark, and, if you will allow

me the time, I would like to make a few remarks. Mr. Owen seems to be adverse to the use of steam-rollers; I think he is right. As a rule, steam-rollers, naturally on account of their construction, are very heavy, and while we all know that a road ought to be rolled well, there is still such a thing as to roll it too well, especially in places where the stone is not as hard as is desirable. There are miles of such places in this country, and you will crush the surface of the road as long as the steam-roller is there. I think Mr. Owen is right in saying that the use of horse-rollers and using them continually for a long time gives a better result.

Another thing that is not always desirable in regard to road-making is to crush the stone by crusher. It is a known fact that stone, especially when it is hard, will pack better if the corners or edges of it are sharp, a result that you seldom obtain by using the stone crusher. If you break your stone by hand you will get sharp corners, and they will pack much better—as the gentleman, in his statement in regard to the excellent roads in India, says that all the stone used there was broken by hand. So it is with the roads I saw in Europe when I was there last. There are others present here to-night who undoubtedly have observed that the roads in France, too, are built to-day, to a great extent, of hand-broken stone. We all know that there is no country to-day which has better roads than France. While in the construction of a new road you may properly use stone broken by a crusher to advantage in the lower layers, afterwards, in keeping the road in repair, it is certainly a fact that hand-broken stone answers the purpose much better, and it should always be used for surface dressing.

There is a road running through Denmark, from north to south, which is called "The King's Highway," and was used as a post road in the old days. It was built about the same time as Macadam appeared in England. It is a very wide road and subjected to a heavy daily traffic. The driveway proper is about 30 ft. wide and macadamized. The depth of the macadam varied from 10 to 14 ins., as necessary. All the stone used in this road is broken by hand. The size of the stone varied from 2½ to 2¾ ins., and each layer was rolled down, water sprinkled, with small horse-rollers. As a surface were used smaller stones, about 1 to 1½ ins. in diameter. I see Mr. Owen recommends that that should be the proper size of broken stones. I agree

with him as far as the upper layer is concerned, but for the lower layer I think the old size recommended by Macadam, who made it $2\frac{1}{2}$ to $2\frac{3}{4}$ ins., answers better.

I notice here in the paper, also, that Mr. Brush makes an objection to macadamized roads because they are so dusty. Most of the roads I have seen built in this country are dusty, sure enough; but you can ascribe this result, to a certain extent, to the use of crushers to crush the stone with; and secondly, to the use of heavy steam-rollers. Their use is cheap, but that is not always a recommendation in public work. The durability of the work should be the first consideration, the cost in regard to material and the appliances used should be the second.

Last summer I had occasion to make observations in Roanoke, Va., for about 5 or 6 miles of streets which were being paved with Macadam. They put down from 6 to 12 ins. of stone. They used the stone crusher, and it broke itself down several times in breaking the stones. A heavy steam-roller was next applied upon a top dressing of screenings. The result was that about eight days after the streets were opened for travel, they were dust clouds in dry and mud holes in wet weather.

Mr. Owen also says in his paper: "After using light horse-rollers constantly a certain time, throw the road open for the traffic; let the travel of wagons, etc., finish it." He is right in this assertion; but we cannot do that in this country as long as we have so narrow tires on the wagons. They do it abroad to a certain extent because they have wide tires. If we should throw open the roads here, with our narrow tires, we would simply destroy them. I think a law was passed in Michigan last year in regard to the width of tires, and I think it would be a very good thing if it was made general.

I shall only make a few remarks in regard to the repair of roads. It is not always necessary to repair the road if it only is looked well after; that means that men should be constantly employed to fill in ruts, clean and keep open the drains, etc. In Europe there are always men employed along the road for these purposes, who, when they have nothing else to do, as in India, sit along the roadside and break stone by hand. The roads there need very little repair because they are always well looked after.

JOHN BOGART, M. Am. Soc. C. E.—Mr. Saabye, what kind of stone was that used in Denmark?

Mr. Saabye.—We used granite, and very hard limestone also. This limestone was somewhat sticky; possessing a mortar-like detritus. When it was rolled down and sprinkled with water, it soon formed a solid mass. I made some chemical examinations of this stone, but I have not my data here with me.

The engineers of the French "*Administration des Ponts et Chaussées*" have made some very carefully conducted examinations of the wearing and crushing qualities of different kinds of stones for road-making, the results of which have compared fairly well with actual experience of the wear in roads. The following table shows these results:

Materials.	Coeff. of Wear.	Coeff. of Crushing.
Basalt	12.5....24.2	12.1....16.0
Porphyry	14.1....22.9	8.3....16.3
Gneiss	10.3....19.0	13.4....14.8
Granite	7.3....18.0	7.7....15.8
Syenite	11.6....12.7	12.4....13.0
Slag	14.5....15.3	7.2....11.1
Quartzite	13.8....30.0	12.3....21.6
Quartzose sandstone	14.3... 26.2	9.9....16.6
Quartz	12.9....17.8	12.3....13.2
Silex	9.8....21.3	14.2....17.6
Chalk flints	3.5....16.8	17.8....25.5
Limestone	6.6....15.7	6.5....13.5

The coefficient..........20 Excellent.
" ....10 Sufficiently good.
" .... 5 Bad.

J. F. O'Rourke, M. Am. Soc. C. E.—I am very sorry that none of the authorities of the City of Poughkeepsie are here this evening, because I think they could add another element to the discussion. The speakers appear to be pretty equally divided between 20-ton rollers and 2-ton rollers. In Poughkeepsie they did better than that; they ignored the question of rollers entirely. They covered almost every street in the city with perhaps 6 or 8 ins. of broken stone, and as you drove along the gutter it looked to be 6 or 8 ft. in some places. Nobody got in anybody's way in the middle of the street for a long time. Now they have first-class roads there and it is to be regretted that the gentlemen are not here to explain how those roads became so good without any rollers at all.

CALVIN TOMKINS.—In considering a road as a floor it should be borne in mind that its efficiency in this respect is largely dependent upon its properties as a roof. This is especially true of comparatively thin roads, and roads resting on bad natural bottoms.

It is possible by making the roadbed sufficiently thick to ignore a wet bottom, but it is cheaper to arrange for a dry base and place a thinner road on it.

Drainage is of the first importance, but the cost of drains can be greatly modified by making the surface of the road as nearly water-tight as possible.

While not disputing what has been said regarding the strength and and durability of trap rock, my experience brings me to the conclusion that hard, broken limestone has a capacity for binding compactly in the road surface in such a way as to make it impervious to water, and that trap rock does not do this so effectively. In any case I am sure that broken trap requires an excessive amount of heavy rolling to effect what can be accomplished with limestone at much less expense.

The photograph of an actual piece of dried-out limestone roadbed (Plate XIV) illustrates this point. I have never seen broken trap, granite or any stone except limestone so compacted that it could be dislodged from the body of the road *en masse*, and still show sufficient cohesive power to hold together when handled. This valuable cohesive property of many limestones is probably due to the solution and subsequent crystallization of carbonate of lime. The cementing action begins as soon as the stones are laid, and the quick consolidation of limestone roads so frequently attributed to the comparative softness of the stone is to my mind in the case of the harder limestones erroneous.

A road may have been properly constructed of clean stone and sharp binder, but insufficiently rolled, or clay and loam may have been used as a binder and subsequently dried out in the summer; in either of these cases the stones in a trap or granite road are likely to become loose and work out of place. This dislodgment of the stones, and the consequent friction arising among them in the body of the road, constitutes one of the prolific sources of wear to which a road is subjected, and far exceeds that of the erosion of travel on the surface of a thoroughly compacted road. As the stones wear round and approximate to clear gravel in appearance, it becomes increasingly difficult to fix

them in place, and the wear is accelerated. Unless roads of this character are carefully attended to in periods of protracted drought this result is more likely to be the rule than the exception. Limestone roads, on the contrary, not only continue compact under the dryest conditions, but consolidate readily in the first instance after the spreading of the stone. As a consequence of the foregoing, the superior hardness of trap-rock is offset in many instances by the increased wearing qualities of a hard limestone road, which does not wear by attrition, and which is likely to be more impervious to water.

While I do not wish to controvert the proposition that a heavily traveled road constructed of clean trap stone and sharp binder and thoroughly rolled is the best road, yet I believe that a road constructed of a hard silicious limestone is more expedient and better adapted to situations where the following conditions, or some of them, prevail :

First.—When suitable limestone can be obtained much cheaper than trap.

Second.—When the heavy and protracted rolling necessary to compact a trap road laid without loam or clay binder cannot be afforded or is impracticable for other reasons.

Third.—On country and suburban roads not subjected to heavy travel.

Fourth.—On side-hill roads subjected to heavy wash.

Fifth.—Limestone screenings are an advantage as a binder in roads constructed of trap and intended for heavy travel.

The excellent roads of Kentucky and southern Pennsylvania are almost exclusively constructed of the local limestones which are so easily adapted to quick and compact road-making, and these roads, I believe, are the oldest metaled ways in the country. In the vicinity of New York City I would instance the country roads about Westchester and New Rochelle, and those surrounding many of the Hudson River towns.

I would also like to call attention to the remarks on limestone roads in the excellent English work of Thomas Codrington, entitled "The Maintenance of Macadamized Roads," particularly to pages 30, 31, 33, 51, 70 and 71.

James Hall, LL.D.*—You refer to a discussion upon Mr. Owen's paper on Macadam roads, and the question of the composition of lime-

* State Geologist, New York, in a letter addressed to Mr. E. P. North.

Sample fragment of Limestone Macadam Roadbed taken out of Main Street, Haverstraw, N. Y., showing cohesive action of limestone.

stones in regard to their working qualities. Nearly all the limestones which are commonly quarried consist principally of carbonate of lime and carbonate of magnesia, with a small admixture of argillaceous and siliceous matter. The wearing qualities depend upon the texture of the rock, the fine grained and compact, wearing longer than the coarser kind. A limestone with any considerable portion of argillaceous matter wears much more rapidly than those where this mineral is in small proportions. A siliceous limestone, or one where there is an unusual proportion of silica in the composition, will wear much longer than the ordinary limestone which is composed almost entirely of carbonate of lime and carbonate of magnesia. The earliest recorded analyses of our limestones, which is accessible to me, is in Dr. Beck's report upon the Mineralogy of the State, published in 1842. Much has been done since that time and published in our scientific journals, but I am not aware that any systematic investigations of this kind have been undertaken until Mr. Smock published his bulletin (No. 10) upon the New York Building Stones. This volume contains more information than any other source to which I can refer you.

Your suggestion that a proper selection of local stone will lead to more road-building than a reliance on trap rock, as a sole material, is worthy of serious consideration. While trap rock may be the most durable material for roads, we find good roads in portions of the country where no trap rock exists; and I believe from what I have seen that a large proportion of the excellent roads in Switzerland and other countries of Europe are made of other material than trap rock. There is one rock in our geological series in the State of New York which makes a better road than any limestone or trap rock which I have seen used. This is known in our nomenclature as the cauda-galli grit, and I would recommend to those interested in road-making that they examine some roads in the vicinity of the outcrop of this rock. Having occasion during last summer to follow the outcrops of our geological formations, especially the limestones of eastern and central New York, for the purposes of my geologic map of the State, I could not help noticing the change in the condition of the roads whenever we approached or came upon this rock.

It occurs to me, however, that I ought to say, in speaking of the cauda-galli grit, that since I have seen it used only on country roads where there is only the ordinary amount of heavy traffic of farmers,

or along roads leading to villages, it might be well to ascertain whether it is such a rock as will bear the heavy traffic over roads within large towns and cities.

EDWARD P. NORTH, M. Am. Soc. C. E.—An apology is due to Mr. Grant for the careless use of one word in my remarks at the reading of Mr. Owen's paper. In the sentence: "There is, however, one to which attention might be called; that is, an unreasoning application of principles of construction suitable in other countries," etc. "Construction," in the limited sense in which Mr. Grant has taken it, is not pertinent to what immediately follows, viz.: the absence of shade on the roads of the Central Park, which do glare in July and August, and it was not my intention to reflect adversely on either the methods, or results of Mr. Grant's road-building.

The system of construction adopted by him nearly 30 years ago for the Central Park roads is still employed in this vicinity without material modification in methods or materials. The roads so built stand, I think, more wear combined with neglect than any other wheelways surfaced with broken stone. They are better made than a Paris street I saw under construction, and are decidedly better than work I saw under construction on the Victoria Embankment, London. This superiority does not lie noticeably in the material employed, as Hudson River trap is not much better than the porphyry used in Paris or the Guernsey granite used in London, but it lies in greater skill in road-building, more honest work in compacting, filling and puddling the roadbed.

Notwithstanding the superior workmanship exhibited in the construction of many of our broken-stone roads, foreigners generally have the better roads to ride over. A determination adopted some time since in Paris to substitute other pavements for broken stone when the annual cost of maintenance exceeded 16 francs per square meter, or $2 57 per square yard, as compared with Mr. Howe's opinion, that a yearly maintenance charge of 1 to 1½ cents per square yard is high, points either to much better road-building by Mr. Howe, or to much more continuous and expensive maintenance in Paris. It is probable that more time is expended on the maintenance of comparatively unimportant roads in Europe than on our best roads, so that the superiority of European wheelways is due more to continuous maintenance than to excellence of building.

It is unpleasant to differ from so much high authority on the subject of narrow tires. Undoubtedly a broad tire is less destructive to a roadway than a narrow tire, both carrying equal loads; but the broad tire with its greater weight is more destructive to transportation than the narrow tire, and roads are built to facilitate transportation. The arguments of the broad-tire reformers will immediately call to our minds the old proverb: "A man who would thrive must rise at five" a proverb which received logical and unassailable amendments through: "A man who would thrive more must rise at four," to the ultimate conclusion that no one should go to bed at all. Opposed to the demand for broad tires is the fact that our wagon-builders combine their skill and materials into the lightest vehicles of equal strength made in the world. And our people have been using them for years. Because a broad-tired wagon, both theoretically and actually, causes less wear on a road than the lighter narrow-tired wagon, legislatures are to be asked to pass laws compelling us to go about our business with a modified road-roller.

It is perfectly practicable to get such a law passed, possibly in several States. A few men may be fined for disobedience of such a law. Probably a great many may be hindered in the transaction of their business for a short time in an effort to enforce it, but the law will never be enforced, and the ultimate result of its enactment will be another case of ill-considered reform, issuing in another law which is treated with contumely and neglect. Most of us will admit that there are already too many such laws on our statute books.

Narrow tires, as pointed out by Mr. Owen, are very efficient in compacting roads. Their great disadvantage lies in the fact that nearly all horses are inclined to take such direction and guidance from any wagon track which they see that the wagon they draw follows the same track, and the compression is objectionably concentrated. While a lazy driver will encourage his horses in this inclination, few will give sufficient attention to driving to sufficiently distribute the compression. Possibly the only practicable remedy for this on a dirt road li in frequently obliterating the wheel marks, so that the travel may b own upon other lines. The ordinary wheeled road-scraper, which does such excellent and economical work in forming and rounding up a road-bed, may be used with even greater economy in moving just enough of the surface of the road to obliterate wheel marks. This plan requires

intelligent and frequent maintenance. On a road made with friable stone, the small heaps, which in such a case should always be on the roadside, can be drawn on for a little material to be placed in any track which is wearing too much.

Reverting once more to "good enough" roads, without objecting to the best roads, it may be asserted that, as a general principle, we will not have the best roads until there is sufficient confidence in their proving remunerative, to induce people to provide the money necessary for their construction. And even with a desire for good roads, there are many localities so impoverished by the high cost of their transportation that it is utterly impossible for them to raise money enough to build a Macadam road. The apostle of good roads who goes into such a community advocating a Telford road costing $15 000 per mile, or even a Macadam road costing $5 000, wastes his time as utterly as one trying to interdict convenient wagons by legislative enactment.

It seems to me that the extension of good roads has been seriously retarded in this country by the too general adoption of unnecessarily thick and expensive roads. When we remember that there are now some 70 or 80 miles of road about Bridgeport that were built under specifications calling for only 4 ins. of road metal, some of which have stood for seven or eight years under considerable traffic, it will occur to many that when an engineer recommends a roadbed from 8 to 14 ins. thick, the soil, or something else, should be carefully examined.

It is unfortunate that in this discussion there has not been a more rigorous specification, in some instances, of materials and methods used in the roads described, *e. g.*, when Mr. Owen spoke of a 4-in. New Jersey road that was "blown up" in consequence of a severe winter spell, it would have added to the general knowledge of road-building if he had mentioned that the road was horse-rolled and clay filled. If a community cannot procure a steam road-roller, they should make a horse-rolled road, when trap rock is used, over 4 ins. thick, on all but sand or well-drained gravelly soils.

I wish to suggest that it is better to build a road that may fail in a few places through deficient thickness, than to build a road so thick that there is no possibility of its breaking through. While the cost of a road does not vary directly with the thickness of metal, it varies very nearly in that ratio, as most of our roads are built on an old road sur-

face, and any unnecessary thickness either locks up money unremuneratively or curtails the length of road which can be built with a given sum, and the value of any road to the community using it bears some not-yet-determined relation to its length. The above suggestion should not be considered in any case where the community does not possess sufficient intelligence to reinforce and repair any weak spots that may be developed.

An analysis of the Dunderberg limestone referred to on page 622 (Vol. XXVII) is given in Vol. VIII of the *Transactions* of this Society, page 98. It is as follows:

Lime	60.20
Alumina	11.22
Silica	6.13
Magnesia	10.45
Carbonic acid	8.00
Water	4.00
	100.00

James Owen, M. Am. Soc. C. E.—Mr. Chairman and gentlemen, I do not know that there is very much for me to say without repeating practically what I said before. I don't see that I have any occasion as yet to acknowledge any very serious or glaring error in my statements or deductions, but incidentally one or two points have been raised, to which it may be profitable to allude.

In the first place I want to endorse Mr. North very strongly in one point, that is, in relation to the wide tires, particularly in the engineering sense. I believe railroad engineers when they design the track, now design it for any locomotive; they do not tell the superintendent of the road that the weight of the locomotives are to be adjusted for the track. In the same way the road engineer should make a road that would take anything that could come upon it. In discussing this question of wide tires any positive action tending to a change is an attack on a vested industry. To pass any legislation that would overturn any practice in a certain line of business is not judicious. In a meeting in my State the question came up and I opposed it there, as I do here, but I presume they will pass it.

I want to allude to a criticism of Mr. Prince with relation to the accepted practice in European countries. I would state that in the

report that was issued last summer with regard to the repairs of roads in the department of the *Ponts et Chaussées*, in France, I was very much surprised and gratified by the fact that that system was almost uniform with the system that I had arrived at. The system was one of repairing in large areas and based upon the practice of making the road as perfect as possible and to maintaining that perfection. Mr. North alluded to the practice of putting on patches of screenings; as I said, a little patching will last a few months and then you have the hole there as before.

With regard to the statement of Mr. Oastler, I should differ very much with his suggestion, that the grading of the roadbed should be level instead of being uniform with the finished surface of the road. I must say that I must plead ignorance to the practice as I have never done it; if you crown the top surface of the road you obviously lessen the thickness at the side with a level bottom, and thereby reduce the amount of the metal and also obviate the drainage which might take place in the bottom of the Telford through the interstices. In fact, I might state here, as to my own practice, that in my specifications for a Telford road 20 ft. wide, when I come to the meeting of two grades I construct on each side to the outlet in the culvert a blind drain; this, if made of Telford, would carry the water passing through the Telford and conduct it to the side, and so away from the end. If I had it level that contingency could not be adopted.

Mr. Saabye's allusion to the question of hand-broken stone, I think, contains a good deal of truth. I have a road of about 9 miles in length which is entirely kept in repair by hand-broken stone. I would state that the stone is broken by a number of gentlemen who sit in a long row and do it with a hammer. They are convicts. They sit there on short seats, and each man breaks about ¼ yd. a day. We get enough stone from them to repair about 9 miles of road. I think there is a superiority in hand-broken stone; it is of a square shape, with a better binding power. I am doubtful whether the economy of the machine-broken stone is better than the hand-broken stone. In the construction of the tunnel of the D. L. & W. road through Bergen Hill they broke all the stone used for ballast by hand; they thought it was cheaper to break it by hand than to crush it by machinery.

I do not think there is anything more to allude to, except that I wish to criticise one point of Mr. Bacot's where he speaks of an 8-in.

Macadam. I wish to submit, with all due respect, that an 8-in. Macadam is anomalous. I build my Telfords of 8 ins., and you can see that it is better when you consider the amount of hammering it has to go through. An 8-in. Macadam is not as economical as an 8-in. Telford. I have built 6-in. Telfords, but I would not suggest that as a practice.

I wish to allude to one thing in the cost of repairs, and that is the difference between an 8-in. and a 6-in. road. In a certain township in New Jersey they are building a number of roads. They started them with the idea of saving money and building 6-in. roads. They found by experience that a 6-in. road that cost 68 cents, I think, originally to build, at the end of three years had to be repaired at a cost of 48 cents. The result was that the arguments for thicker roads prevailed, and now no roads thinner than 8 ins. are built, and at the end of last year they had a balance in the treasury of $4 000, due to the less cost of repairs in 8-in. roads.

Mr. North.—Was that road made with the horse-roller?

Mr. Owen.—Yes, sir.

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ASPHALTUM FOR RESERVOIR LININGS.—DISCUSSION ON PAPER No. 566.*

By R. C. GEMMELL, C. B. BRUSH, S. WHINERY, J. F. FLAGG, W. B. PARSONS, R. L. HARRIS, FOSTER CROWELL, M. FARGUSSON, F. COLLINGWOOD, E. P. NORTH and J. F. O'ROURKE.

R. C. GEMMELL, Assoc. M. Am. Soc. C. E.—A description of the asphaltum-lined reservoir for the city water works of La Grande, Ore., may be of interest in connection with Mr. Schuyler's paper. This reservoir was planned about a year ago by my partner, Mr. A. L. Adams, and myself, and was constructed during the summer of 1892.

The reservoir is oval in form, part in excavation in heavy, clayey soil, and part in embankment made from the excavated material, with inner side slopes of 3 to 1. The depth of water is 10 ft., area of surface 20 880 sq. ft., and capacity 1 000 000 galls. The lining consists of one layer of brick, laid dry on edge, covered by a layer of bitumen $\frac{3}{8}$ in. in thickness.

* "The Use of Asphaltum for Reservoir Linings," by James D. Schuyler, M. Am. Soc. C.E., Vol. xxvii, page 629.

After the earth had been excavated and embankment made, the whole inner surface of the reservoir was thoroughly tamped with iron tamps weighing about 25 lbs. and having end areas of about 28 sq. ins. The bricks were then laid on edge and settled solidly into place by tamping, the joints and cracks being brushed full of clean sand. Coal tar was used as a flux, the proportions being 1 part of tar to 8 or 9 parts of California rock asphaltum, by weight. As the reservoir was in a certain sense an experiment, there was some question as to the proper percentage of flux that should be used, the idea being to use as small a percentage of tar as possible. The mixture was "cooked" in a semi-cylindrical kettle, about 8 ft. long by 4 ft. wide by 2 ft. deep, set up between 8-in. brick walls, with bottom of kettle about 18 ins. from the ground. A "batch" consisted of about 1 600 lbs. of asphaltum, with from 10 to 12% of tar added. Each batch was cooked five or six hours, being continually stirred until the mass became liquid and homogeneous. A large bucketful at a time was then taken out of the kettle by two men, and spread in a thin layer over the bricks by means of shovel and broom. It required two layers put on in this way, to make the requisite thickness of $\frac{3}{8}$ in. As much sand as would adhere to it was sprinkled over the last layer while it was yet hot.

During the progress of the work I made a number of tests of the tenacity of the asphaltum by dipping the ends of two bricks in the mixture, pressing them together and allowing the asphaltum to cool, then breaking the joints. In each case the asphaltum remained intact; and the joint broke by a thin layer of the end of the weaker brick stripping off and adhering to the asphaltum. Through carelessness, a rock about 6 ins. in diameter was shoveled out of the bucket with the asphaltum and allowed to remain until it had cooled. I instructed the men not to try to break the rock off, for fear of damaging the lining; but one of them misunderstood me and struck the rock a heavy blow with a sledge. It broke off all around where the asphalt gripped it, with no appearance of damaging the lining.

This reservoir has never leaked. During the process of excavating, two or three very small springs, or rather "seeps," were discovered in the bottom of the reservoir and in the sides close to the bottom, and it was thought best to tile drain the bottom. This was done, the pipe being brought out through the entry trench together with the other

pipes and connected with the overflow pipe below the gate well. Only a little trickling stream came from these "seeps" through the drain, and after the water had been turned into the reservoir no difference could be noted in the discharge; hence, the above statement that the reservoir has never leaked seems justifiable. The lining was considered a success, but liquid asphaltum, instead of coal tar, should have been used as the flux.

The cost of the lining, including the asphaltum, tar, bricks, sand, wood and labor of mixing and spreading the asphaltum and laying the bricks was about 12¾ cents per square foot. The labor averaged $2.25 per day for man, and $4 per day for man and team, ten hours.

A description of a small asphaltum-lined reservoir for the City Water Works of Waitsburg, Wash., just completed (January 22d) may also be of interest. This reservoir we planned after Mr. Schuyler had kindly given us by a letter a description of the asphaltum-lined reservoir built at Denver. It is constructed part in excavation in light, ashy soil and solid rock, and part in embankment made from the earth excavation, with inner side slopes of 2½ to 1. The depth of the water is 10 ft., area of surface 12,000 sq. ft., and capacity about 420 000 galls. The lining consists of one layer of the asphaltum and sand paving 1½ ins. thick, covered by a layer of pure asphaltum about ⅛ of an inch in thickness.

After the excavation was completed, the hollows in the surface of the rock excavation were filled in with puddle, well tamped; and the whole of the inner surface of the reservoir was brought to a proper slope and grade. The embankment was, during the process of construction, watered, rolled and wheeled over, to make it as solid as the nature of the material would permit without actually puddling it, and before the paving was put on, the inner surface of the reservoir was thoroughly rolled with an iron roller weighing a little over 800 lbs.

Las Conchas asphaltum was used as a flux, the proportions being 2 parts of it to 8 parts of rock asphaltum. The asphaltum was cooked from 10 to 12 hours, and then mixed with clean, sharp sand in the proportions of 1 part of asphaltum to 5 parts of sand, by weight. The sand was first heated to a temperature of about 200° Fahr., and the mixing was done in the sandpan by four or five men with hoes and shovels. This was done within a few feet of the reservoir site, and the mixture was delivered in place by wheel-barrows at a

temperature ranging from 300° to 340° Fahr. It was then spread out in a layer of uniform thickness with hot rakes and thoroughly rolled with the 800-lb. iron roller, which was kept hot by means of a charcoal fire in the pan hung inside of the roller. The paving was put on in vertical strips, the edge being painted with pure asphaltum each time before the next strip was put on, thus probably making the joints stronger than any other part of the paving.

After water had been standing in this reservoir about five days, a break occurred in the lining near the bottom over the entry trench, and the water worked its way out along the pipes and around the concrete cut-off walls. Investigation showed that the first joint in the drain pipe from the reservoir, just inside of the first cut-off wall, had not been caulked. The end of the pipe was plugged up, and this joint leaked badly under very small pressure. The supposition is that, during the five days the water stood in the reservoir, the leakage from this joint was sufficient to cause the earth in the entry trench next to the lining to settle away from it, leaving the lining alone to stand the pressure of the water in the reservoir. Great care was taken in back-filling the entry trench, to water and ram the material thoroughly; but it was a difficult matter to make a solid bank of such light, ashy earth. The hole in the lining was about 6 ins. in diameter, and around it the lining was dished in like a bowl, showing the great tenacity of the material. I found that on one side of the hole the lining had, in the distance of 7 ins., bent in 4 ins. below the face of the reservoir without cracking. The reservoir has been repaired at a comparatively small cost by the original contractor, who was still on the ground.

The cost of the lining, including asphaltum, sand, wood and labor, was about 12½ cents per square foot. The labor averaged $2 per day for man and $3.50 per day for man and team, nine hours.

The rock asphaltum used at Waitsburg averaged in weight about 86 lbs. per cubic foot, and the mixture of liquid and rock asphaltum, after being boiled 10 or 12 hours, then poured in a mould and allowed to cool, weighed about 77 lbs. per cubic foot. A series of experiments to determine the proper percentages of flux and rock asphaltum that should be used, the best proportions of the asphaltum and sand, and the proper length of time for cooking the asphaltum, would be interesting and useful. With this in mind we prepared a number of

sample bricks, but have not yet had an opportunity to test them. The percentage of asphaltum used at Waitsburg was not high enough to give the best results. In my judgment at least 20% of asphaltum should be used, and 25% would be better.

CHARLES B. BRUSH, M. Am. Soc. C. E.—The paper is very interesting. It treats of a subject in relation to which we have had very little experience, or, at least, I have had very little experience. If it is true that reservoirs can be lined with asphalt in the way described, at half the cost of ordinary lining, and that the reservoir can be made impervious to water and at the same time can stand such a test as is described in this paper, that of allowing the water to freeze and become fast to the asphalt, and all this without injury to the asphalt and without impairing the water-tight character of the lining, it is certainly something that requires very serious and earnest consideration.

Another feature which has been referred to is the ease with which a repair is made in case of a leak. I am not familiar with the paper—I have just glanced over it hastily—but if I remember correctly, it was stated that an opening 100 ft. in length and 6 ins. wide was repaired at a very small cost, some $20, I think.

If that is a fair indication of the ease and economy of repairing such an opening in the side of a reservoir, it certainly is a very interesting fact and it will be appreciated by anybody who has been called upon to repair a leak in a bank of a reservoir; such a repair is usually made at an expense that runs into thousands of dollars rather than hundreds.

This is the first time that I have heard this question intelligently discussed. I have heard many claims, but I have never seen the subject presented in so clear a way. I hoped that some of those who are familiar with the use of asphalt might have been with us to-night and would talk with us on the subject. It is unfortunate for us that Mr. Schuyler is in the extreme West where we cannot get at him and ask him questions. Our friend, Mr. Whinery, is with us to-night, and perhaps can, without attempting to discuss the paper, which is possibly a delicate matter for him to do, inform us a little further in relation to the uses of asphalt in this country. As described here it seems as though it would be perfectly feasible at any location or in any locality to construct a lining for a reservoir as described in this paper. There would seem to be no reason for not doing so, and yet, perhaps, there may be.

Whether there is anything in our eastern climate which differs from the western which would make a lining of this kind not advisable is something which we would all be interested to know. In the clear, dry climates of the extreme West a great many things are done with cement and asphalt which do not seem to succeed with us. For instance, stucco plastering of houses in New York City is a perfect failure; it has always been attended with most unsatisfactory results, while the stuccoing of houses in the West seems to be entirely satisfactory. Whether there is anything in the moist climate of the East near the seashore, or whether there is anything in the rapid changes in temperature in connection with the moist climate which would have a similar effect on the use of asphalt for lining reservoirs as it does on the stuccoing of houses, would be an interesting inquiry. It is certainly very important that we should learn all we can in connection with the matter, and I would like to ask Mr. Whinery the simple question, whether, in his experience with asphalt, anything has led him to suppose that if these results obtain in the West, as described in this paper, they would also obtain if applied in the East, and also whether the probability of durability is sufficiently great to warrant the use of such a lining for a reservoir in this eastern section of the country. If Mr. Whinery could enlighten us to any extent on the subject we would all be very much pleased to have him do so, or if any one else in the Society could contribute to the discussion on this subject, he would certainly be a public benefactor to all who are engaged in trying to make reservoirs water-tight.

Samuel Whinery, M. Am. Soc. C. E.—About five years since, some two weeks after I first became interested in the asphalt business, a member of this Society who was then constructing the new water works at Covington, Ky., came to me to ask whether it would be practicable to line the new reservoirs with asphalt. I knew almost nothing about the subject at the time, but in thinking over the matter there occurred to me some objections. The time allowed to discuss or consider the project was so short that it was concluded to drop the matter.

One of the questions which occurred to me then was this: like all other substances in Nature, asphalt contracts with cold and expands with heat. Now, while the asphalt lining of a reservoir would not be exposed to the same range of temperature that asphalt pavements are

on streets, still it would be exposed to very considerable changes in that respect. Certainly the change from the warmth of ordinary reservoir water in summer to a temperature perhaps many degrees below freezing is very considerable. Last winter I undertook, rather unsuccessfully, to determine the coefficient of expansion and contraction of asphalt in the form in which it is used for pavements. The results were quite contradictory and not at all satisfactory. As nearly as I could determine from those experiments the coefficient of expansion is about half that of wrought iron. We propose to repeat those experiments in a different form this winter and hope to determine, at least approximately, the coefficient of expansion of the material.

In summer time the contraction of the material would make little difference, because it would be sufficiently malleable to draw out or compress, as might be necessary, without breaking; but at low temperatures, say, 30° Fahr., or perhaps lower, depending upon the richness of the mixture and consistency of the bitumen, it might become so brittle as to crack instead of yielding or drawing out. I would think that during very cold weather in winter when the reservoirs were frozen to a depth, as I understood Mr. Schuyler to state, of 18 ins., there would be danger of small cracks forming, which, of course, would allow leakage through the reservoir covering to some extent.

There was one other feature about which I had some doubt. Pure bitumen is impervious to water, but when you mix it with sand you make a more or less porous mass which is not perfectly impervious. The best Trinidad asphalt pavements will absorb from 3 to 4% of water; like all other substances of a porous nature, the material will gradually soften. A street, for instance, paved with asphalt if not exposed to travel, or in the gutters where there is little or no travel, gradually shows a disposition to soften and become more porous; whereas, in the middle of the street, where it is subjected to the compressive effect of travel, this tendency is effectually counteracted. I would be afraid that in the course of time this asphalt coating, particularly if made up with a large proportion of sand in its composition, might become more or less porous and gradually soften and lose its perfect resistance to percolation. I think the method described in the paper of applying the material is probably as effective as any other. There would be a very delicate question as to what was just the right mixture of bitumen. We find that a variation of 1% in the amount of oil used

for tempering the bitumen in the composition for paving purposes is sometimes sufficient to determine whether the resulting pavement is good or bad. If I wished to line a reservoir with this material, I should make a careful series of experiments to find just the proper composition for the purpose. I now see no good reason why a coating of asphaltic concrete made in this way, quite rich in bitumen and made of the proper consistency and properly put on, should not make a very effective lining for reservoirs, and I think it would be reasonably permanent. I think Mr. Schuyler's figures as to the cost would be a safe basis to estimate upon. It is possible that a lining of the thickness he used might be put on for considerably less than the figures he gives, but even at that cost it would not be a very expensive experiment, and it is one well worth trying by all water works engineers.

I ought to repeat that I have had no experience in this character of work, and only judge from my general knowledge of the material.

Mr. Brush.—I would like to ask one question. Mr. Whinery spoke of asphalt concrete and said that it would be desirable as a lining. Does he mean a concrete formed of broken stone and asphalt?

Mr. Whinery.—No, sir; formed of sand and asphalt. That is a general term in the asphalt business, paving material being often called asphaltic concrete. There is a material distinctively known as bituminous concrete, which is made up of coal tar and sand and broken stone.

Mr. Brush.—I want to ask Mr. Whinery if he would have a greater feeling of security as to the lining of the reservoir if it was laid upon a concrete 4 to 6 or 8 ins. thick, of stone and asphalt or tar or any proper mixture, and then this lining put on the top, whether he would feel any more security in the bank than if the lining were put on the earth. I am not now speaking of the security of the bank, but rather of the security of the asphalt, and for the purpose of enabling the asphalt to be put on clean.

What I wish to ask is, whether he would have any greater faith in the lining of the reservoir if the coating of stone concrete mixed with asphalt or cement or tar, or any other mixture, were put on the bank, and the asphalt put over it, and, if so, which mixture he would prefer?

Mr. Whinery.—I would say the asphalt coating must have a sufficient support. The pressure is not very great, so that if the support is uniform and of the strength of ordinary compressed clay I think it

would be sufficient, provided you felt sure the clay would not settle. What you need, in using a coating of that kind, is some rigid surface on which to put it. Not necessarily a surface of very great strength, but one that will sustain the load without failure or settlement. If you have a bank that you are sure will not settle, it will afford sufficient support for the asphalt lining. If you think the bank is not secure, then a hydraulic concrete foundation would be better.

Mr. Brush.—I asked the question because I have never seen a reservoir bank that is homogeneous. I have never seen one that would not settle more in one place than in another. I could not understand, as this paper was read, how an earthen bank could be made sufficiently rigid to hold this lining which it seems to me must act unsatisfactorily if the bank was not uniform in its make-up. That being the case, it seemed to me almost indispensable to the satisfactory working of this lining to have something of the nature of concrete under it. I am glad to have Mr. Whinery speak so confidently on the subject, because, unless we can get this ideal bank to support the asphalt lining, we have got to put on a coating of concrete of some kind to support it.

J. Foster Flagg, M. Am. Soc. C. E.—I would like to ask for a little more information relative to the tendency of the asphalt to wrinkle on the slopes of the reservoir walls. The author says: "although it manifests a tendency in warm weather to creep and gather in wrinkles down the slopes in both reservoirs, it never breaks and remains impervious to water." Would not this creeping and wrinkling be cumulative, and would not, therefore, the rupture of the coating be only a question of time? Even on pavements with a slight slope there is this tendency to creep. I have seen samples from the asphalt pavements of Washington with marked corrugations in them. With the steep slopes of reservoir banks, although below the water-line, the water would doubtless exert a beneficial influence, I should think this action would be much more rapid. The experience, it seems to me, is too short in time to form a positive opinion as to the durability of this coating.

Mr. Whinery.—In reference to the difference between the Trinidad and California asphalts, the California asphalt is a very variable article, and unless one could see the samples he could form very little opinion of it. On the Pacific coast, as I am informed, it is found of every consistency, from practically a crude petroleum up to the

hardest pitch or bitumen. Not only does the consistency thus vary when pure, but it is found in various degrees of impurity, mixed with sand and clay; it is not uniform like the Trinidad asphalt.

In reference to wrinkling, in asphalts which contain a considerable amount of oil, volatile at ordinary temperatures, the oil will to some extent evaporate, and the coating might become hard, or wrinkle, very much as does coal tar. In the Trinidad asphalt there is such a very small percentage of volatile oil that when exposed to the air it does not change perceptibly for years, and I would say, that if the coating is made of the proper consistency there would be no danger of that kind. When Trinidad asphalt paving material is taken out of the streets after years of use, it apparently has nearly, if not quite, the same degree of plasticity as when put down.

Robert L. Harris, M. Am. Soc. C. E.—As to the matter of thin coating of asphaltum on a thick backing of concrete, is it not as well to avoid the latter? That is, does not the thin coating of asphaltum, being flexible in degree, adapt itself to the settlement and slight changes in the bank similarly to the skin upon animals, and so prevent leakage in case of slight changes, by reason of not breaking, as would concrete when its support should fail?

Foster Crowell, M. Am. Soc. C. E.—My impression in listening to the paper was that, with reference to the two reservoirs that were last described, the author speaks of the treatment with asphalt not being so necessary in one case, because the banks had had longer time to settle.

Mr. Whinery.—I would say, further, in reply to Mr. Brush, that the cracks referred to by Mr. Schuyler doubtless resulted from settlement, and a very considerable amount of settlement must have occurred to produce them. A small amount of settlement would hardly cause them. Asphalt is malleable to a remarkable degree, and the lining of a reservoir deflects without breaking so as to accommodate itself to slight settlements in the supporting bank. If there was unequal settlement in adjoining sections of the bank it would doubtless cause a break.

Wm. Barclay Parsons, M. Am. Soc. C. E.—It is to be regretted, possibly, that the author, in writing this very interesting paper, has not gone a little further and stated from his personal experience how far he would dare to carry the principles he lays down.

Under certain conditions we know that it is possible to construct large banks that will not leak. There are other cases where a good puddling material can be had only at great expense, so that the difference in cost between constructing an asphalt-lined embankment and one that is water-tight in itself would be considerable. Now, would Mr. Schuyler dare to build a bank not water-tight and line it with asphalt, or would he simply use the asphalt lining as an adjunct to a so-called water-tight embankment? If an embankment can be built out of non-water-tight materials and then lined with asphalt, it would in many cases reduce the cost materially.

There is another point that occurred to me—the effect the asphalt would have on the growth of plants. I suppose upon the ordinary floating algæ it would have no effect whatever, but on plants that require a soil it would have some effect, until at least a deposit of soil deep enough for them has been formed. The cleaning out would probably remove most of the bed soil, and, therefore, it is fair to presume that a reservoir so lined would be freer from plant life than a reservoir not so lined.

Mr. Brush.—The impression from reading the paper and from some remarks that have been made this evening would seem to indicate that there was a feeling that asphalt was one of those materials that would accommodate itself to circumstances; if there was settlement, it would stretch; if there was a slight contraction, it would contract. A somewhat similar idea prevailed when they were building the Washington Bridge. There is a long arch there of metal which rises and falls, and the rise and fall of the arch chords necessitate a movement at the abutment, and in order to meet that movement, when it was decided to put asphalt in the roadway, an iron trough was placed on the abutment where the iron-work arch closed against the masonry, and this iron trough was filled with asphalt. The theory was that, as the arch rose and fell, the asphalt of the roadway would accommodate itself to it and there would never be any opening at the joint. If any of you have been there you will see that the asphalt did not work that way. My experience with asphalt, though very limited, does not convince me that it is as accommodating as would seem to be indicated by the paper now under discussion.

M. Fargusson, Jun. Am. Soc. C. E.—That, I think, depends on the time element. While a rapid distortion would cause a rupture, a dis-

tortion equal in amount, but taking place slowly and gradually, would not necessarily so do. Because cracks are developed in asphalt laid on a metallic structure of very long span subjected to great extremes of temperature in short periods of time, and hence to fairly rapid and often repeated distortions, it in no wise follows that the same results would be effected by the slow final settlement of an embankment carefully built and already well consolidated.

J. F. O'Rourke, M. Am. Soc. C. E.—Has anybody here had any experience in laying vertical walls with water-tight material?

Mr. Brush.—I do not know whether I can answer the question; but in building walls, in order to keep the water out in one house, and in order to prevent the ground water from getting into an excavation I had made, I put up two brick walls, leaving them about 1½ ins. apart and filling in with coal tar; it worked satisfactorily. If the gentleman means a plastering put on the outside, I have not done that.

Mr. Fargusson.—The Consolidated Telegraph and Electrical Subway Company, of New York City, had the utmost difficulty in making their manholes water-tight.

Eight-inch brick walls laid in cement mortar and coated inside (and outside too, I think) with a lining of the same, failed utterly to keep the water out. As an experiment, one of the worst of them was coated inside with an asphaltic compound, the proportions of which I do not know, but which was quite hard and of a very fine and even grain. It was put on quite thick, I suppose about ½ in., perhaps it averaged a little less. It answered the purpose perfectly up to the time I last saw it.

Mr. O'Rourke.—The point I wanted to get at was whether you could take a wall that is surrounded by water on the outside and permanently keep the water out by means of an asphalt coating. The gentleman has answered me in regard to keeping the water out of a manhole. I would like to ask him if that was permanent?

Mr. Fargusson.—I do not know.

Mr. O'Rourke.—How long has it lasted?

Mr. Fargusson.—It was put on in 1888 or 1889. What its present condition is I cannot tell. I have not seen it since a few months after it was finished, at which time it was without cracks and perfectly tight. Perhaps, there is some one connected with the Subway Company here who can tell us more about it?

F. Collingwood, M. Am. Soc. C. E.—We speak about a wall of this kind being permanent. The question, in my mind, is whether any asphalt wall is permanent? Whether in these walls there is not a little change which takes place in all asphalts by which they become brittle and lose their tightness?

Mr. Whinery.—I presume that there is a very little change, particularly in some asphalts. Perhaps the best evidence on that point is the fact that what is known as the Pitch Lake in Trinidad has apparently lain there for ages, and so far as we know it has undergone but little change, and it must have maintained about the same consistency for a long series of years. They to-day find when they dig into it that it grows a little softer below the surface.

Mr. O'Rourke.—That is one point. Anybody who has taken the trouble to observe an asphalt floor or sidewalk, after a time will see that the crack that started in one year the next year will be larger. In Central Park, I think, you will see cracks opened 3 or 4 ins. which in the first place were hair lines. I think that is evidence enough that there is constant shrinkage going on.

So far as asphalt plaster on the inside of a wall keeping the water out is concerned, I know it cannot be successfully done in that way, for the pressure would, in time, force it off. If you caulk a boat from the inside it will fall out, and no one ever did any permanent caulking on that side successfully, and if that be true of caulking, how much more of plastering? I think this question is a very important one, and you have got to decide that you can do it, and know what you can do, and the way to go about it before adopting the idea of depending on asphalt to prevent water from penetrating masonry. I have given my reasons for thinking that a coating on the inside will not exclude water under a head; therefore, I believe that it should only be used, if at all, where it can be properly applied on the outside or in the interior of the wall. In regard to laying asphalt or anything else upon earth, what Mr. Brush says is a fact of which I have had the best evidence. For a number of years I was connected with paving in this city, and some work over gas mains laid in Broadway was paid for at a high price in order that it should be done and finished and need not be touched again. They would ram the earth, go over it and make it as hard as possible, and also put in the strongest kind of a concrete foundation, but without avail. It had all to be repaved the next year.

E. P. North, M. Am. Soc. C. E.—Are not the Park walks made with coal tar?

Mr. O'Rourke.—Some of them are, but those that I spoke of are not.

Mr. Whinery.—Mr. President, there is another explanation of the fact that cracks in an asphalt pavement, when once formed, grow larger, than that the material shrinks. In some northern cities asphalt pavements do crack during the extreme cold weather of winter. When the crack forms it becomes filled with dirt and gravel compacted by travel and when the summer heat comes the pavement expands, but the crack, being packed up with sand, cannot close up and must compress. The next winter when the pavement contracts again you will have, of course, a little wider crack. In this way the cracks often do grow wider, but I do not think that it proves that the material itself gradually shrinks. In milder latitudes such cracks do not occur.

Mr. O'Rourke.—It is good enough evidence though of the fact that it gradually cracks.

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ELECTRIC ROCK BLASTING.—DISCUSSION ON PAPER No. 561.*

By SPENCER MILLER, SAMUEL WHINERY, JAMES OWEN, GEORGE R. HARDY, A. McC. PARKER, EDWARD P. NORTH and E. E. R. TRATMAN.

SPENCER MILLER, Assoc. Am. Soc. C. E.—In reference to the 1 200-ft. cable-way used at Ogden, N. J., by T. A. Edison, I would add some data respecting the handling of iron ore there. Three hundred and fifty to four hundred tons per day are actually handled, and the cost of operating cable-way, to hoist, convey and deliver the material to crusher, does not exceed $7 per day or about two cents per ton.

The cable-way, receiving its support entirely outside the working limits of the mine, is entirely unaffected by blasts of the heaviest kind, and as soon as the blast has been fired, the work of filling the skips may begin. Thus the cost of blasting and handling material is reduced to a minimum by the use of the cable-way.

* "Electric Rock Blasting—The American Method," by William L. Saunders, M. Am. Soc. C. E. Vol. XXVII, page 530.

I do not understand that I violate any confidence in giving some costs as taken from the books of the Concentrating Company.

A two weeks' run showed the entire cost of drilling, blasting labor, filling the skips, blacksmith labor, clerical labor and the entire cost of running the cable-way, to be $21\frac{1}{2}$ cents per ton. The cost of the powder is $2\frac{3}{4}$ cents per ton, making a total of $24\frac{1}{4}$ cents per ton. I am told that the entire cost of mining, including stripping, is about 31 cents per ton, including interest and depreciation, the latter being 1 cent per ton.

The cost of filling the skip is five cents per ton.

Mr. Saunders mentions the work at the Chicago Drainage Canal. I take pleasure in stating that a portable cable-way of new design will be used on this work, several having already been contracted for. I hope at a later day to be able to present to this Society the cost of this work per ton or cubic yard with this portable cable-way.

Samuel Whinery, M. Am. Soc. C. E.—About 12 years since, I had quite a large experience in blasting rock, both in water and in quarries. In this work we used electricity for igniting the blasts, and, it being Government work, we kept an accurate account of the cost, and everything else of interest about the work.

In one large quarry where we were procuring stone for a rip-rap dam, we had a rock face about 50 ft. high ; the stone, was solid limestone, the ledges from 6 to 12 ft. thick. The stone, when blasted out, was loaded on flat boats at about the level of the bottom of the quarry and had to be moved an average of about 60 ft. The heavier masses were handled by derricks, and the smaller portions by wheelbarrows. The actual cost of work at the quarry, including all labor, tools, materials and quarry superintendence, was $28\frac{4}{10}$ cents per cubic yard. The quantity of rock moved was obtained by cross-sectioning the quarry at the beginning and the end of each month, and computing the amount of solid rock removed. The work was kept up for at least three months in succession, at about the cost named above.

Mr. Saunders, I think, underestimates the importance of testing the fuses. I think that some sort of instrument for testing the circuit in each exploder is exceedingly desirable. We used, for thus testing fuses, a rude galvanometer made by surrounding a pocket compass with a few coils of insulated copper wire, actuated by a single cell of Leclanché battery. It was arranged so that the circuit was completed through the fuse by slipping the bright end of each wire into spring clips con-

nected with the terminals of the instrument. The slightest deflection of the needle showed that the connection through the fuse was intact.

A single defective fuse in a line of blasts may result in the loss of 15 or 20 minutes of time for all the men employed, while they are out of the quarry, waiting for the defect to be hunted up, and the blast fired. It is therefore important that every fuse should be known to be perfect before it is used.

I think there is a general impression, which is quite incorrect, as to the necessity of insulating the leading wires. The fact is, that with naked copper leading wires, 100 ft. or less in length, lying in the water, at least four of these fuses can be fired with a good plunge battery. This seems quite incredible until it is tried. I had devoted a good deal of thought to the matter, and had, as I imagined, devised a very nice method of completely insulating connections. It was simply to take a piece of soft rubber tube and slip it over one of the wires, and after the wires were twisted together it was slipped back over the joint and tied tightly at each end with a bit of cord. In the course of a few days after we began blasting in water I found the men were neglecting to thus properly cover the splices, and I called attention to it, and was told that they found it was unnecessary where only three or four blasts were in the circuit. Of course the explanation is, that the water is so poor a conductor, as compared with copper wire, that, with the low tension current used, the leakage of current amounted to very little It is hardly ever necessary, even in wet weather, to insulate the connections in ordinary land blasting.

In regard to tamping blast holes, there is little question as to the proper method in ordinary land blasting. We had quite an experience in securing a proper tamping for submerged holes. We were blasting with holes about 2½ to 3½ ft. deep, where the top of the rock was submerged about 18 ins. In that case we found water tamping was insufficient. We found that ordinary sharp sand did not give a very good result, as the water seemed to act as a lubricator, and it was driven out with very little effect. We tried a great number of things ; among others, we tried running plaster of paris into the hole though a tube, and allowing it to set for about half an hour before firing it. This did excellently, but it was impracticable to get the men to use it properly. Finally we came back to using screened pebbles about as large as grains of corn.

In blasting with the higher explosives, I think it will be found in

almost every case, that a very large quantity of the material is wasted, that the charges are made very much heavier than necessary. In using dynamite the quantity required is so small, that it is almost impossible to get the average foreman to put in only the quantity required. After trying a number of schemes to prevent the waste of explosives, I finally made a gauge, which was simply a rod of wood, one side of which was graduated with feet and tenths. On the adjacent side, opposite each mark, the length in inches of dynamite cartridge required for that length of line of least resistance in the blast to be fired was indicated. For instance, opposite 1 ft. there might be ¾-in. dynamite; opposite 2½ ft. there might be 3 ins. of dynamite. The foreman was instructed to use this gauge by laying it on top of the rock in such a way as to measure, as nearly as possible, the line of least resistance, and then the quantity of dynamite marked opposite that figure was used. We found that we reduced the quantity of explosive used in the quarry about one-half; this was in the open quarry. Of course it would not be practicable in blasting under water.

JAMES OWEN, M. Am. Soc. C. E.—You don't remember what your proportion was?

Mr. WHINERY.—I do not. I used the ordinary formula with coefficients determined by trial. It was some 12 years ago, and I do not remember accurately.

GEORGE R. HARDY, M. Am. Soc. C. E.—How was the test made with the wire, in fresh or salt water?

Mr. WHINERY.—Fresh.

A. McC. PARKER, M. Am. Soc. C. E.—For the last three years I have had occasion to use considerable high explosives in the city work at the foot of One Hundred and Twenty-fifth Street. We are blasting to get a uniform depth of 12 ft. below water, and at high tide that brings it down sometimes as deep as 17 ft. below the surface. We have had the same experience that Mr. Whinery speaks of in regard to insulation. We led directly from the diving scow and thought it would be quite important in salt water to see that the joints and connections were all fairly insulated and covered up. We have fired as many as six or seven holes in salt water without any attention being paid to the connection. The wires were simply scraped bright with an old knife. It has been a peculiar experience with us that in the explosive which we are using it has happened quite frequently that

the detonator has gone off and not fired the explosive. We are using rack-a-rock there, because it is in the city limits, in the neighborhood of several manufacturing establishments which have been burned out once or twice and they are a little uneasy about dynamite, but do not seem to care at all about rack-a-rock, and the fire insurance people do not raise any objection. I don't think anybody has ever had any experience in which a detonator has blown out of a dynamite cartridge and not set off the charge, unless it was so badly frozen that it was inert. But in rack-a-rock we have found that the detonators will go off and we will pull up the wire and no explosion has taken place, except that of the cap. We have not had any trouble about breaking, when we have gotten our charges right. There has not been much difficulty about losing the charge, but it has happened on several occasions. We have always been blasting in such deep water that there was no trouble about the tamping. We have had occasion, however, to blow up several boulders in the Harlem River that would show at low tide. They broke in just the shape we wanted them, 8 or 9 ton pieces, but they were fired at high water, when the charges were tamped with fuses on 5 ft. of water.

Edward P. North, M. Am. Soc. C. E.—In regard to losing dynamite blasts in cold weather as mentioned by Mr. Parker. In some underwater blasting, under my direction, a No. 1 dynamite cartridge had its top knocked off by an 8 or 9 grain detonator without apparently firing any part of the cartridge. It was a very cold day, below zero, the top of the cartridge was about 18 ins. below the top of the rock, which had 4 ft. of water on it, and some oakum was tied to the top of the cartridge, to prevent its being lifted from contact with the cartridges below it through floating ice striking the leading wires.

On seeing that it was a misfire I took a boat and found the top of the cartridge on the rock by the side of the hole. A second cartridge was taken and the same style of exploder, reinforced with a 9-grain fulminate cap, was placed from one-third to one-half the depth of the cartridge, which was then tied up with a wad of oakum, as before.

Although this must have occasioned a delay of fully half an hour, during which the temperature of the main charge should have got down to 32° Fahr., the shot when fired was apparently as effective as any single shot with the same charge fired at that place.

Some experiments, which were made both before and after this, led

me to think that thoroughly frozen No. 1 dynamite could be fired, if efficiently confined, by 15 or more grains of fulminate, but that no amount of fulminate that can be pushed into a cartridge will fire it when frozen and unconfined. The experiments, however, were roughly made.

E. E. Russell Tratman, Assoc. M. Am. Soc. C. E.—In his remarks upon explosives used in blasting, Mr. Saunders makes no reference to the use of unfreezable dynamite to prevent the numerous accidents which occur from the careless way in which frozen cartridges are thawed. Probably many minor accidents of this kind occur which are not reported in the papers ; but the accident on December 28th, 1892, at the works in Brooklyn, N. Y., for the proposed tunnel under the East River, where the cartridges were thawed out in a steam chest, and 40 lbs. of dynamite were exploded in consequence, several lives lost, and great damage done, is one of the periodic occurrences which come as reminders of the danger and uncertainty of dynamite. The unfreezable dynamite is, I believe, a German invention, the principal feature of which is said to be the addition of a small percentage of isoamylic nitrate to the nitro-glycerine or dynamite, rendering it uncongealable and somewhat less sensitive to concussion, while at the same time slightly increasing its explosive power. About two years ago I met in England an expert in explosives who had conducted satisfactory tests of this material, and who gave me some instances of the singular carelessness displayed by men in thawing cartridges by baking, boiling or otherwise heating them. I have recently received information from a gentleman connected with the invention in England, stating that the material does not freeze at a temperature of 50° below zero, Fahrenheit. It is manufactured in the same way as ordinary dynamite, and the cost of manufacture is about the same. It is not affected by damp or shock, and samples which were made two years ago and have been subjected to the ordinary alternations of heat and cold have recently been found to have undergone no change whatever in regard to the non-freezing quality.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

583.
(Vol. XXVIII.—February, 1893.)

STREET MOTORS ON THE GOVERNMENT TRAMWAYS AT SYDNEY, NEW SOUTH WALES.*

By GEORGE DOWNE, M. Am. Soc. C. E.
READ MARCH 1ST, 1893.

The writer does not propose to discuss the relative merits of different systems of tramway traction, but to give only the details of cost of working steam motors in the City of Sydney, as these are seldom given with the fullness desired by engineers.

There are five main lines leading into this city, all joining into one at a point about three-fourths of a mile from the terminal station. From these main lines there are eight branch lines, three of which have engines running to and from their junctions only. The engines of the remaining five of the branches run over the main lines to the head terminal station. On every line there are many curves, ranging from 80 ft. to 196 ft. radius and grades up to 6%; and fully one-third of the lines, both main and branch, are constructed on grades ranging from 3 to 5%, the last named predominating.

* The subject-matter of this paper was sent in the form of a letter to the Secretary, and in view of its value in connection with the recent discussions on the subject, has been prepared by him in its present form.

All trains arriving at or departing from the main station pass over the same lines up to the junction at Hyde Park. It may be said that a proper tramway system should be less centralized, and should be worked with small cars and a quick headway; but in Sydney, for various reasons, centralization could not be avoided when the lines were constructed.

The following rates are paid to employees on the running staff: to drivers, 11s. to 14s. per day; firemen, 7s. 6d. to 9s.; cleaners, 4s. 6d. to 7s. 6d. per night. For these, 55 hours constitute a week's work. To the repairing staff the wages are: fitters, 10s. to 13s.; blacksmiths, 10s. to 12s. 6d.; turners, 10s. to 11s. 6d.; car-builders, 10s. to 11s.; machinists, 7s. 6d. to 9s.; laborers, 6s. 6d. to 7s. per day, 48 hours constituting a week's work. These amounts form an important item in comparisons of working cost.

There are now in use 106 motors for working the city and suburban roads, 93 of which were built by the Baldwin Locomotive Works, 10 were built locally on American patterns, and three were by English builders. All are 4-wheel, coupled. About 80% have 35-in. wheels, and 11 x 16-in. cylinders, and 67 of this number are now in ordinary daily traffic. The cost of the locomotive branch of the service for the year 1892 is given in detail in the following table:

New South Wales Government Tramways—Locomotive Branch C and S Lines.

Statement showing the Mileage performed by Steam Motors and the Working Expenses of the Locomotive Branch, with the Cost per Train Mile for the Financial Year of 1891-2.

Particulars.	1892.
Total No. of motors in stock (average for the year)	106.35
In steam daily;—Traffic	61.85
Shunting and ballasting	3.00
Average No. of motors under repair	23.91
Average available reserve	17.59
Total engine mileage run	1 885 303
Total train mileage	1 607 308
Average total mileage per motor	17 727
Average total mileage per motor in steam	29 072

EXPENDITURE.

Head of Service.	Total Cost 1892.	Cost per Train Mile 1892.
Locomotive Superintendent and Clerks.	£ s. d.	d.
Locomotive superintendent, etc.	593 5 3	.088
Clerks and messengers	582 8 1	.087
Accou nting staff	323 7 4	.048
Drawing office	17 7	.000
Stationery and printing	70 7 5	.011
Repairs to head office	5 9	.000
Office cleaning and sundries	92 10 9	.014
	£1 663 2 2	.248
Locomotive Foremen.	£ s. d.	d.
Inspectors, running foremen, etc.	1 373 8 11	.205
Timekeepers, running staff	350 0 0	.052
	£1 723 8 11	.257
Locomotive Drivers and Firemen.	£ s. d.	d.
Drivers and firemen	40 865 1 0	6.102
Drivers' expenses	10 12 6	.002
Holidays	1 673 11 3	.249
Sick pay	47 13 9	.007
Relieving	1 467 12 3	.219
	£44 064 10 9	6.579
Locomotive Cleaners, Coalmen, etc.	£ s. d.	d.
Cleaners	5 106 12 5	.763
Running shed laborers	1 298 6 2	.194
Storemen	145 0 0	.022
Fuelmen	1 904 4 5	.284
Holidays	336 17 10	.050
Sick pay	4 18 9	.001
Relieving	84 4 3	.012
	£8 880 3 10	1.326
Locomotive Sundries.	£ s. d.	d.
Tools and machinery	99 17 5	.015
Gas, candles and oil lighting	1 162 7 5	.173
Electric light in running sheds	891 5 0	.134
Sundries	122 17 0	.018
Casualties	2 15 11	.000
Repairs to yard lamps	5 4	.000
Repairs to running sheds	144 15 0	.022
Holidays		.000
	£2 424 3 1	.362
Coal, Coke, Wood, etc.		
Fuel for locomotives	£15 664 3 3	2.339
Water.	£ s. d.	d.
Water supplied to the Department	1 801 15 8	.269
Wages, repairs of water supply pipes	136 7 0	.020
Materials " " "	113 3 9	.017
	£2 051 6 5	.306

EXPENDITURE—*Continued.*

Head of Service.	Total Cost 1892.	Cost per Train Mile 1892.
Oil, Tallow, Waste.		
	£ s. d.	d.
Oil, tallow, waste and other running stores	3 663 10 5	.547
Stores for Cleaners.		
	£ s. d.	d.
Stores for cleaners	562 3 1	.084
Engine Repairs.		
	£ s. d.	d.
Wages and materials	24 417 0 2	3.645
Proportion of shop charges	3 936 18 9	.588
New engines to maintenance	*Nil.*	.000
	£28 353 18 11	4.233
Car Repairs.		
	£ s. d.	d.
Wages and materials	9 035 8 11	1.349
Proportion of shop charges	977 9 4	.146
Examining cars	227 18 0	.034
New cars to maintenance	*Nil.*	.000
	£10 240 16 3	1.529
Wagon Repairs.		
	£ s. d.	d.
Wages and material	85 15 11	.013
Proportion of shop charges	20 16 7	.003
	£106 12 6	.016
Grand Total	£119 397 19 7	17.828

To understand the table it should be stated that the trains are run with one to four cars each, as the traffic requires. The average number of cars per train was 2¼. These cars are standard, and each seats 70 passengers. This makes an average seating capacity of 158 persons per train, and the average weight of a loaded train 82 880 lbs. This explanation is necessary, since the cars ordinarily employed seat only from 16 to 24 each.

The motor service is thought to be very satisfactory, averaging per motor 29 072 miles per annum in steam, with an average speed of 10 miles per hour. All the under-gear is exposed to dust in dry weather, and mud in wet. Fully one-eighth of the number in steam make a daily run of 100 to 130 miles, and the average for all in steam is now over 80 miles per day. The state of efficiency in which the stock is maintained can be gathered from the fact that at Easter and Christ-

mas, the longest holiday seasons, the motors not available for traffic were only 1%, and of cars $2\frac{1}{2}$% of the total numbers.

From the report of the Railway Commissioners for 1891–92 it will be seen that the total working expenses for the year were £229 145, of which £119 398, or something more than one-half, was expended by the locomotive branch, of which details are given in the table above, and £73 318 was for salaries and wages to roadmen, conductors, etc. The total working expense per train mile was therefore $34\frac{8}{100}$d., and the portion due to the locomotive branch $17\frac{83}{100}$d.

In comparing these expenses with those in other localities, it is necessary to note that, in addition to the weekly pay, every employee is paid for his time during all holidays proclaimed as general in the Colony, and, also, in the case of a large portion of the running staff for three to six good-conduct holidays.

The proclaimed holidays average at least 11 per year, so that all the staff is paid for 11 days, and the running staff for 14 to 17 days more than he works, a concession beyond anything granted by private companies.

Notwithstanding the rates paid for labor, the increased cost for materials imported from England and America, and the concessions granted under the control of the present Commissioners during the past three years, a net profit of over 5% per annum has been realized in addition to the expenditure of large sums out of revenue in renewals of road and stock.

The fares are collected in sections, some at 2d., others a penny; the average rate being slightly under a penny per mile.

All the employees are under civil service regulations, and must retire at the age of 60, unless after medical examination the Commissioners think it desirable to retain them. A son cannot work under his father after his salary reaches £80 per year.

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XXVIII.—March, 1893.)

JETTY HARBORS OF THE PACIFIC COAST.*

By THOMAS W. SYMONS, Captain, Corps of Engineers, U. S. A.

READ MARCH 15TH, 1893.

The improvement of harbors on the Pacific Coast of the United States by the jetty system has reached such a stage, and has been so successful at several points where the work is now practically completed, that it has occurred to me that a statement and general description of the conditions met with, the plans of improvement adopted, their execution, the results obtained and the lessons learned, might be of interest to my brother engineers.

The Pacific Coast.—The Pacific Coast of the United States is generally high and rocky, with few good harbors. Enormous masses of easily moved sands form the shores, and underlie the waters adjacent thereto. The extent of shore line from the southern limit of California to the northern limit of Washington is 3 120 miles, divided as follows: along California, 1 097 miles; along Oregon, 285 miles; and along Washington, 1 738 miles. This latter includes the shore lines of the mainland and the islands of Washington and Puget Sounds.

* Discussions on this paper received before May 15th, 1893, will be published in a subsequent number.

Upon this great extent of coast, the only first-class harbors are at San Francisco, the Columbia River, and in Puget and Washington Sounds. The number of harbors of any kind along the main ocean shore is very limited.

Ocean Slopes.—As a rough approximation, it may be stated that the slope of the bottom of the ocean in the immediate vicinity of the land averages above four fathoms per mile. The distance of the 100-fathom curve from the shore diminishes generally from north to south. Along the State of Washington it averages about 20 miles from shore; along Oregon, about 10 miles, and along California, about 6 miles. To the south from Monterey Bay, the 100-fathom curve averages not more than 4 miles from shore.

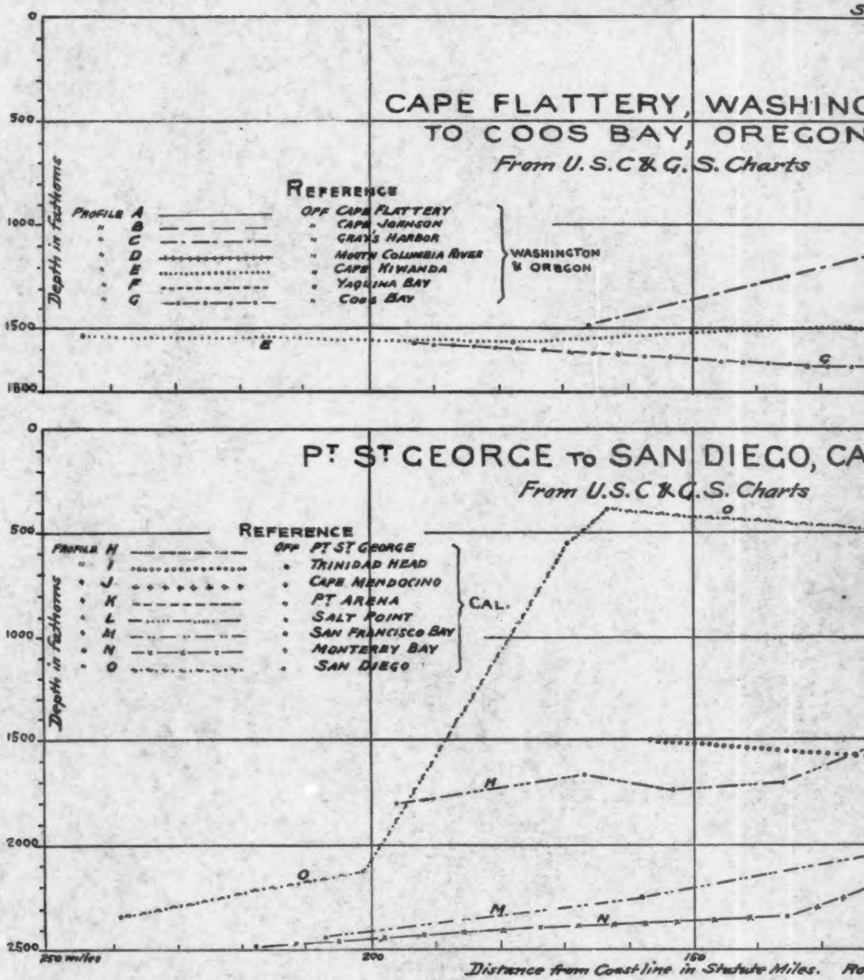
As the prevalence and severity of storms increase from south to north, it is probable that to this fact are largely due the flatter slopes of the fore shore on the northern coasts. Beyond the 100-fathom curve, the ocean deepens more rapidly, a depth of 1 500 fathoms being reached at an average distance of 60 miles from shore, giving a slope, to reach this depth, of 25 fathoms per mile.

Plate XV shows a number of ocean profiles taken from the Coast and Geodetic Survey Charts. These profiles show how much steeper are the ocean slopes, and how much deeper the ocean becomes, as we go from north to south. The profile marked "*O*," taken from San Diego, exhibits the great ocean plateau lying at a general depth of 500 fathoms to the south and east of Santa Barbara, which includes within its limits Santa Rosa, Santa Cruz, Santa Catalina, San Clemente, and other lesser islands.

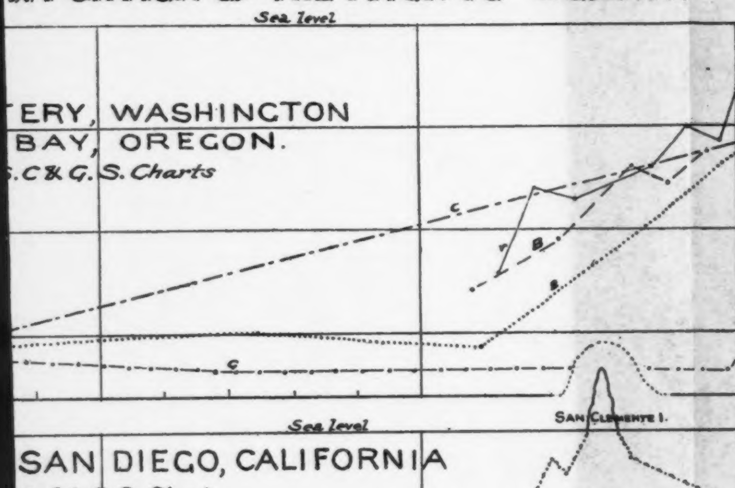
Currents.—The main drift of the waters off the coast is from the north-westward. This is the flow of the great Japan stream after striking the northwest coast. The great ocean current produces a reflex eddy coast current to the northward. This northerly inshore eddy current is established by much cumulative evidence. It is stated by Professor Davidson, that 9 out of 10 of the buoys that go adrift off the Columbia River go ashore to the north at distances varying from 20 to 100 miles. A remarkable instance of this drifting to the north is that of a large nun buoy, which went adrift from the Columbia River bar in January, 1889, and traveled in 167 days 1 540 miles up into the waters of Alaska.

Along some parts of the coast, this northerly current is continuous

PROFILE OF A PORTION OF



A PORTION OF THE PACIFIC OCEAN.



ast-line in Statute Miles. Round black dots indicate located soundings.

PLATE XV.
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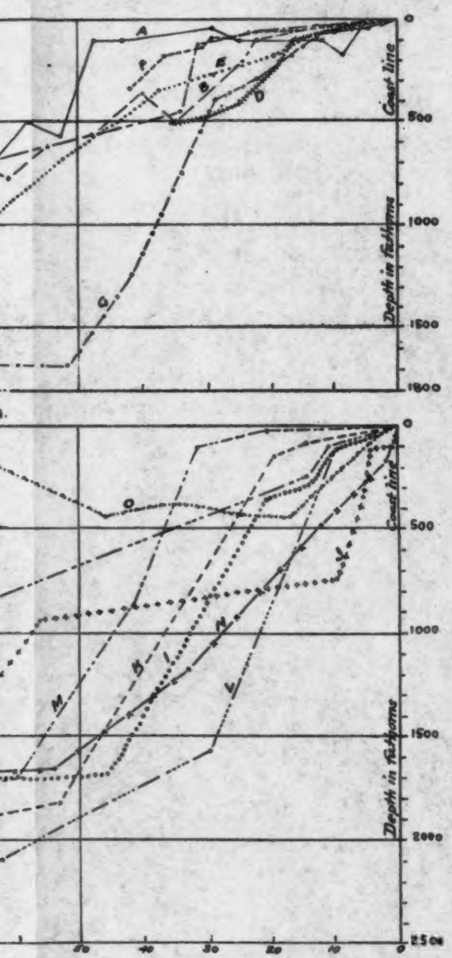


throughout the year, but in many other parts it is modified by the shape of the coast and the prevailing winds. During the summer, along the shore, the prevailing winds are from the north and northwest, while the winter and most severe winds are from the south and southwest. The surface currents near the shore are modified and controlled by these winds, the currents have the same direction as the winds, and often reach a velocity of 1½ to 2 miles per hour. These currents, controlled by the winds, extend off-shore to distances estimated at from 16 to 50 miles. They are again modified by the projecting capes and bights, establishing eddy currents. Our knowledge of the ocean currents of the Pacific Coast is in reality very limited, as no systematic and detailed study of them has ever been made, although such study is highly important for engineering and navigation purposes.

Professor Davidson, of the Coast and Geodetic Survey, has endeavored for years in vain to secure funds to carry on the requisite observations. All the engineers and assistants along the coast are instructed to and do study these currents, but the range of observation is so limited, and the data gathered so scattered and disconnected, that the results obtained are by no means satisfactory.

Tides.—The tides along the Pacific Coast of the United States are of a complicated character. In general, they increase in range from south to north, the mean range at San Diego being 3.7 ft., and at the mouth of the Columbia, 6.2 ft. In Puget Sound these heights are much increased. At Olympia, situated at the head of Budd's Inlet, the tide often reaches a height of 18 to 20 ft.

There is a marked peculiarity of these tides not observable in those of the Atlantic Coast, this being the difference in the heights of the two high and two low waters of each day. In each lunar day, there are two high waters and two low waters, which are generally unequal in height and occur at unequal intervals. These are ordinarily designated as the "lower low," "higher low," "lower high," and "higher high" waters. They succeed each other along the main coast as follows:

From the lower low water, the tide rises to the lower of the two high waters; then falls to a low water that is higher than the preceding low one; then rises to the higher high water; then falls again to the lower low water. Sometimes there is scarcely any difference

between the "lower high" and the "higher low," so that the tide is apparently at a standstill for many hours. In the inner waters of Puget and Washington Sounds the order of occurrence of these tides is reversed, and the differences become still more marked.

A datum plane adopted by the Coast Survey and the Engineer Department is the mean of the "lower low" waters. This is ordinarily about 1 ft. below the plane of mean low water, as it would be determined upon the Atlantic Coast.

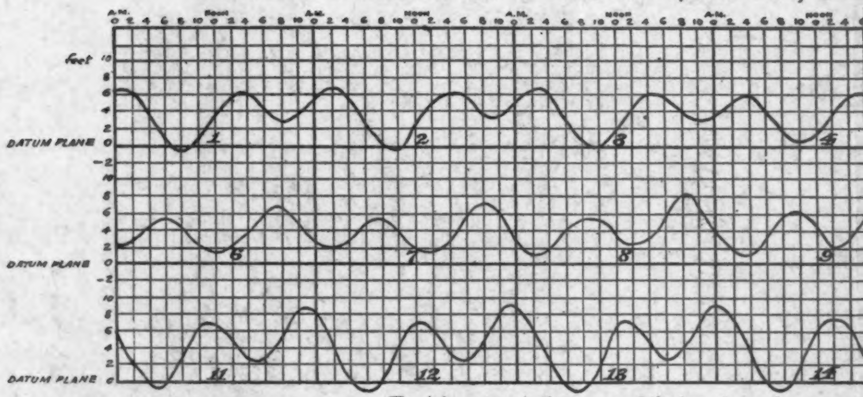
Plate XVI shows the peculiarity of the tides as exhibited on a self-registering tide gauge for 15 days at Yaquina Bay, and for 15 days at Seattle on Puget Sound.

Shores.—The Pacific Coast is generally high and rocky. The main bulk of the rock along the coast is sandstone of various degrees of hardness; here and there a point jets into the ocean, which is sufficiently hard to resist the action of the seas. Some of these projecting points are of hard trap rock. The grinding up of the rocky coasts by the seas has supplied the Pacific Coast very liberally with sand. The coast range of mountains, the summits of which are at an average distance of about 20 miles from the shore, are composed mostly of sandstone, of which a great portion is soft and easily eroded. The sand resulting from these two causes has accumulated along the shores in vast quantities, to be the plaything of the winds, waves and currents, and to render necessary most of the works which have been undertaken for the improvement of the Pacific Coast harbors. The visible sand occurs in the form of glistening dunes, entirely bare of vegetation, of great areas just above high water, upon which drift-wood is scattered, and upon which a scanty vegetation seems endeavoring to get a foothold, and of large areas exposed at low tide. Besides the visible sand, there is that forming the fore shore, the shoals and bars, and held in suspension in the ever-moving waters.

To control, properly and efficiently, this sand is particularly and primarily the object of most of the improvements on the coast.

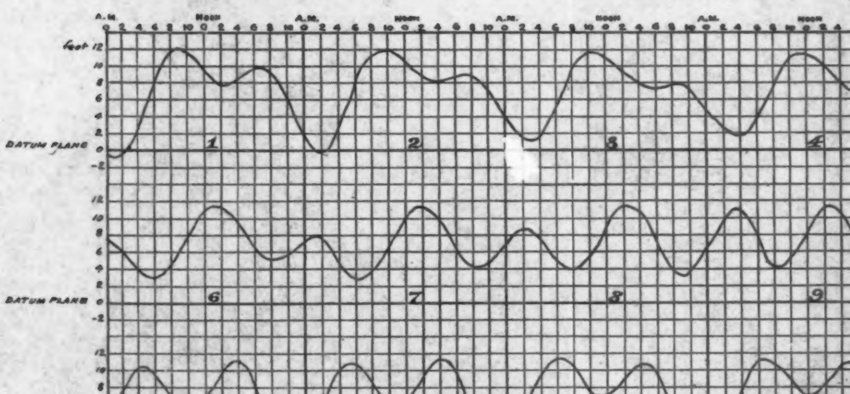
A careful study, therefore, of the movement of these sands in air and water is necessary in order to hit upon the best plan for improvement in any particular locality. In some places, as at Coos Bay, the sand moves in a regular cycle, being washed up on the spit, and the elevated sandy peninsula limiting the bay on the west. Here it is dried to a greater or less extent, and then moved by the northwest winds

Graphical Representation of Tides at Yaquina Bay, Ore



The datum plane is the mean of the lower low waters

Graphical Representation of Tides at Seattle, Washington



The datum plane is the mean of the lower low waters

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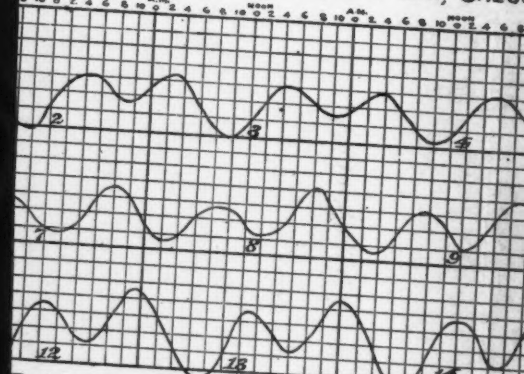
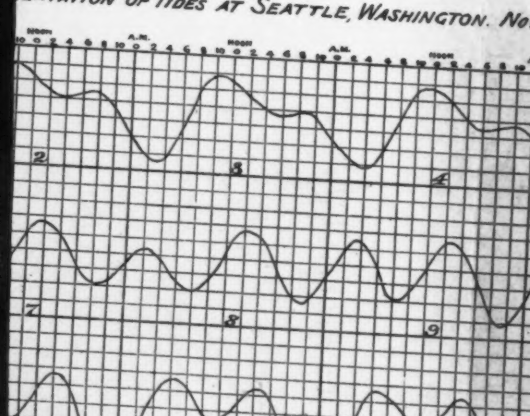
ESENTATION OF TIDES AT YAQUINA BAY, OREG



The datum plane is the mean of the lower low waters

SENTATION OF TIDES AT SEATTLE, WASHINGTON. NO



datum plane is the mean of the lower low waters

PLATE XVI.
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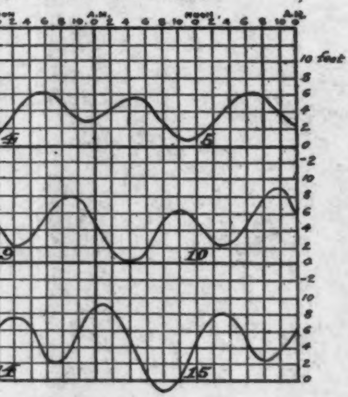
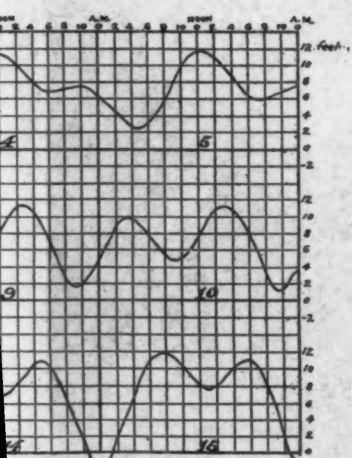
OREGON. JUNE 1885



GTON. NOV. 1890



of summer or the southwest winds of winter across and over into the bay. The tidal ebb currents sweep it out to sea, and it is deposited upon the bar to be again torn up by the waves and forced back upon the shore, to resume its cyclical movement. As an auxiliary to the regular jetty harbor work at Coos Bay, an effort is being made to control and limit this sand movement by establishing plant growth on the sandy peninsula. This effort is still in its experimental stages, but it is evident from these experiments that it requires only money and time to accomplish great good in this manner. This was also done to a slight extent at Wilmington.

The quality of the bar sands has also an important bearing upon the question of improvement. If the sand is heavy and coarse, like it is at the entrance of the Coquille River, it is with much greater difficulty that a channel is scoured through a shoaled-up bar than it is where the sand is fine and light like that at the mouth of the Siuslaw River. But in the latter case shoaling is more apt to take place under wave action, and consequently a bar channel is less stable when once formed.

Drift.—The abundant forests of Washington, Oregon and Northern California send down to the sea an enormous quantity of drift timber, which in some instances is an important factor and has to be given serious consideration in devising works of harbor improvement. The whole of the North Pacific Coast is lined with this drift, consisting of logs, 4 to 6 ft. in diameter, and 100 ft. or more in length, intermingled with stumps and smaller forest debris. Where works are situated at the mouth of a drift-bearing stream, special precautions have to be taken, to prevent injury to the auxiliary and uncompleted work by the drift. The photograph of the improvement works at the mouth of the Coquille River (Plate XVII) shows a typical view along the North Pacific Coast, and gives a slight idea of the enormous quantities of drift in many places along the coast.

Harbor Improvements.

The necessities of commerce have demanded that a number of harbors along the coast be improved, and the Government has appropriated money to this end. At two points along the coast, Port Orford in Oregon, and San Pedro in California, it has been proposed to make harbors for deep-sea ships by means of breakwaters, but they have never been commenced. A number of harbors have been, and are being, im-

proved by the construction of jetties, and this is the particular class of improvement with which this paper has to do. It is believed that a knowledge of the works and the results obtained can best be communicated by giving a few examples.

The inauguration of the jetty system, pure and simple, on the Pacific Coast, took place at Yaquina Bay.

Yaquina Bay.—Yaquina Bay is a narrow estuary some 20 miles long, situated on the Oregon coast, 115 miles south of the Columbia River. The improvement of this bay was demanded in consequence of the building of the Oregon Pacific Railroad, and the desire of the people of the Willamette Valley to have an outlet to the sea and the markets of the world separate from, and independent of, the outlet by way of Portland and the Columbia River. The tidal area of Yaquina Bay and river, and all sloughs affected by the tide, is 5 square miles. The total drainage area of the bay and all its tributaries is 262 square miles. Except in heavy freshet stages, the fresh-water flow is of relatively no importance compared with the tidal flow.

The average height of the tides above the plane of reference, the mean of the lower low waters, is 7 ft., with an extreme range from lowest to highest of about 11 ft. There is a mean ebb outflow of 32 000 cu. ft. per second, more or less, as the tide is spring or neap. In its natural condition, the harbor throat lay between a rocky headland on the north, and a low, sandy point on the south. The channel discharged into the ocean over a sandy bar underlaid by, and interspersed with rocks. As far as known, there was always at least one channel over the bar, carrying about 7 ft. at low water. Sometimes this channel lay in a north-westerly direction, and at other times in a south or south-westerly direction. At times, two channels were found, doubtless with diminished depth. These channels were always narrow, uncertain in alignment and depth, and bordered by sands upon which there were constant breakers. About a mile in front of the shore, and about a quarter of a mile in front of the outer edge of the bar, is a reef of rocks extending nearly north and south, upon which there is a low water depth, varying from 6 ft. to several fathoms. The heaviest of the westerly swells are broken by the reef before they reach the entrance of the bay. This reef has a very important bearing on the improvement of the entrance, acting as it does as a breakwater protecting the entrance and the jetties.

PLATE XVII.
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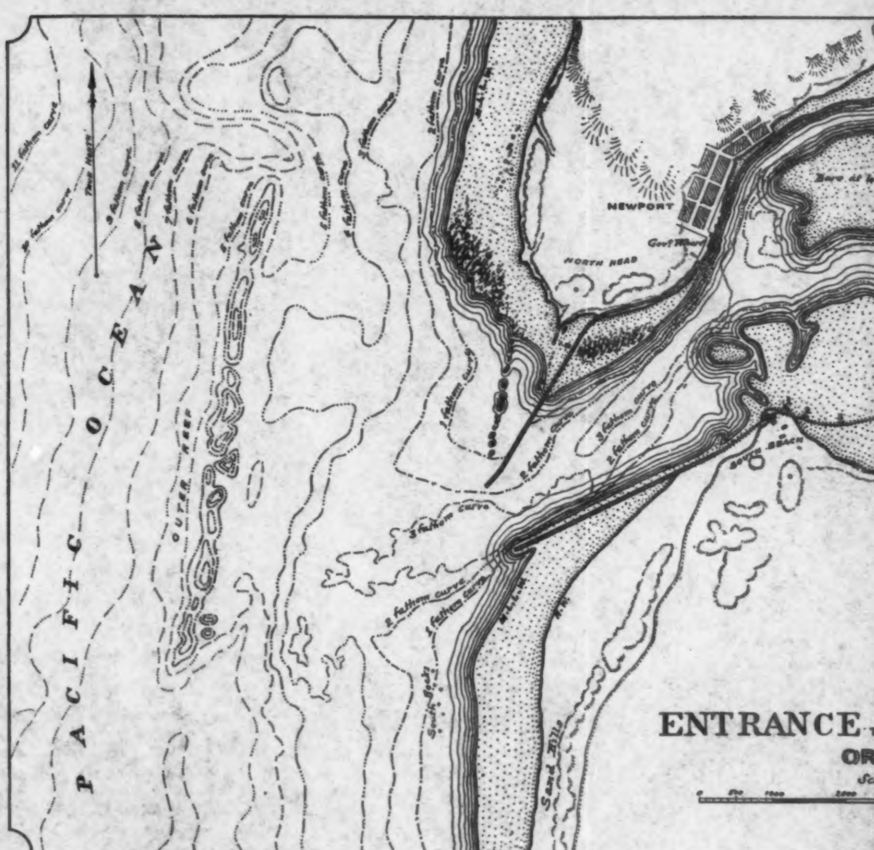
Between the bar and reef the depth was from 4 to 5 fathoms. Outside the bar, the depth increased seaward very slowly to the outlying reef; beyond the reef, the depth increases more rapidly. Borings through the sand indicated the whole entrance to be underlaid with rock in nests, ridges, or in a stratum, or all combined. The highest point of rock found in the vicinity of the proposed channel was 18 ft. below the datum plane. These borings, made through from 8 to 15 ft. of sand, gave but imperfect knowledge of the underlying rock, but enough was learned thereby to indicate that the maximum depth to be expected from scour was 18 ft.

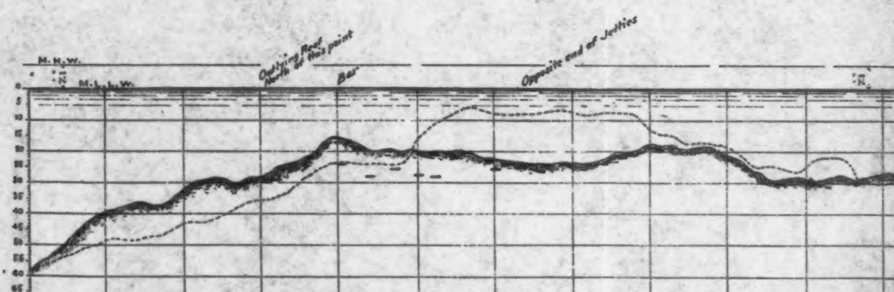
The entrance opens upon the stormiest part of the coast, where heavy gales prevail at intervals, from November to April. These storms develop waves of great magnitude, which break, or, in other terms, assume a motion of translation, in depths of 8 to 10 fathoms. The summer winds produce waves of much less magnitude, which are harmless in depths greater than 3 or 4 fathoms. On this sandy coast, these violent waves produce great effects. In the act of breaking and the rush that follows breaking, they displace great masses of sand and carry it shorewards, often closing with greater or less completeness for a time the outlets of rivers or estuaries. The same effect is produced in less degree by the more northerly winds of summer. It is in this connection that the outlying reef is thought to be so valuable to the Yaquina entrance.

Plan of the Work.—The plan finally adopted for the improvement of the entrance to Yaquina Bay is shown on Plate XVIII, and consists of two jetties starting at the harbor throat, about 2 300 ft. apart, and converging to a distance apart of 1 000 ft.; the north jetty to be 2 300 ft. long, and the south, 3 600 ft. long. The considerations governing the locations in plan were, 1st, to give the shortest available route to deep water for the entrance channel, the outlying reef rendering it necessary to deflect this channel to the south, to facilitate vessels passing out around its end; 2d, from the best information available, the entrance channel was in its best natural condition when in this position; 3d, the location chosen was the most favorable of all in reference to the rock underlying the sands; 4th, the location and direction causes as little interference as practicable with the littoral drift of water-borne sand; 5th, the extension was calculated to drive the bar out to deeper water, and, at the same time, keep it well within

the protection of the outlying reef; 6th, the width of 1 000 ft. at the extremities of the jetties corresponds fairly well with interior widths; 7th, gives reasonable facility to vessels seeking entrance; 8th, gives ample water-way for the flooding tides to fill the tidal compartment; 9th, does not contract the ebbing and flooding waters sufficiently to produce a dangerous scour and active undermining along the jetties; in fact, 10th, the converging form of the plan tends to accumulate sand along the inner portion of the channel sides of the jetties and thus protects them from undue scouring; and 11th, the jetties are so located that they can be extended, or the space between their ends narrowed, if it should ultimately be found desirable so to do.

The jetties are rubble mounds, built up to high water. The south jetty is built on sand, and is supported upon a brush mattress about 4 ft. in thickness. The north jetty enrockment rests directly upon the bed-rock underlying the harbor entrance, and so no brush was used in its construction. The method of building the jetties is by means of a pile tramway with two narrow-gauge tracks over which the piles, brush and stone are transported, and from which the brush mattresses are made and the stone dumped. The general form of tramway is similar to that shown for the Columbia River (Plate XIX. The south jetty tramway was built for the greater part of its length with the pile bents 10 ft. apart, and 10 ft. space between the center of the tracks. The later construction, adopted at Yaquina Bay, has 15 ft. between the pile bents and 14 ft. between the centers of the tracks. The four piles in each bent are spaced so that each pair will furnish as direct a support as practicable to the longitudinal roadway bearers. These piles are capped with cross-timbers 12 x 12 ins. x 22 ft. Upon these are placed the longitudinal roadway bearers 12 x 14 ins. x 30 ft. in length. These are all drift-bolted together. Directly upon the longitudinal bearers the rails are placed, no ties being used. Rails, 30 lbs. to the yard, are used. The gauge of the tracks is 3 ft., and they are spaced 14 ft. apart from center to center. The distances between the bents and tracks permit the rock to be dumped from either track toward the center as well as toward the outside of the tramway. The piles are driven by a revolving pile-driver, mounted upon four diamond trucks running upon the double track. The over-reach of the driver is sufficient to allow the piles to be driven 15 ft. in advance of the tracks.

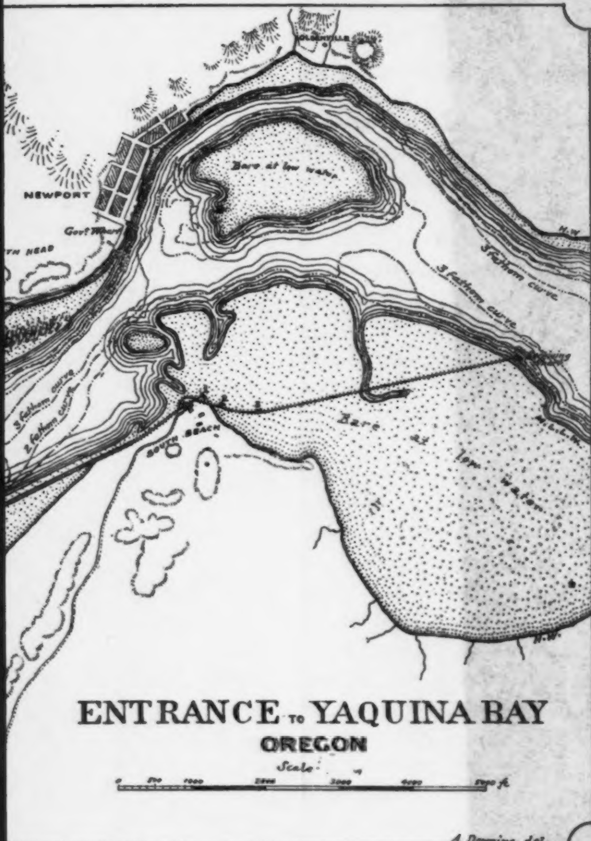


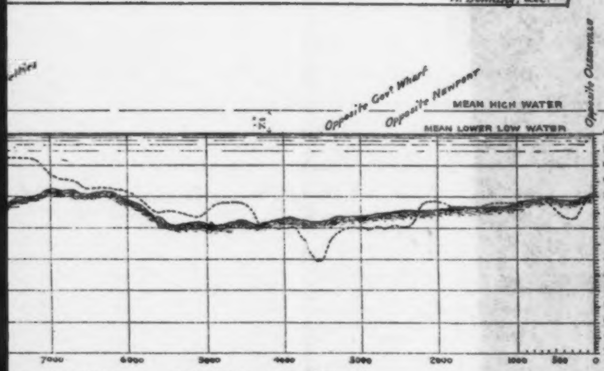


PROFILE OF YAQUINA BAY, SHOWING PRESENT AND ORIGINAL CON

Present bottom of Channel indicated thus:- *Bottom of Channel preceding improvemen*

Horizontal and Vertical scales in feet
Rock borings indicated thus —





...NG PRESENT AND ORIGINAL CONDITION.

Bottom of Channel preceding improvement indicated thus

...rtical scales in feet

...icated thus —

The revolving motion is given to the driver by a pinion working into a large cog-wheel, concentric with the circular track upon which the machine revolves. At the top of the pinion shaft is a wooden bull-wheel and a rope around this is taken to the winch head of the engine whenever it is desired to turn. The hammer guides are 44 ft. long, and the hammer weighs 3 600 lbs. When driving in sand at Yaquina and other points along the coast, the hydraulic method is now used exclusively.

In building the north jetty tramway, rock was met with throughout its length; what sand there was, was scoured away in advance of the jetty. Some of this rock was soft enough to permit piles to be driven in from 2 to 8 ft., but the last 1 200 ft. would permit no penetration. In this portion the method pursued was to place each pile of a bent in position and immediately brace and tie it to those previously placed. The four piles of a bent being so placed, the track was extended over the new bent, the pile-driver run back out of the way, and the dumping of rock about the new bent commenced. This was continued until a considerable quantity was distributed about the foot of the piles; then another bent was added in the same way.

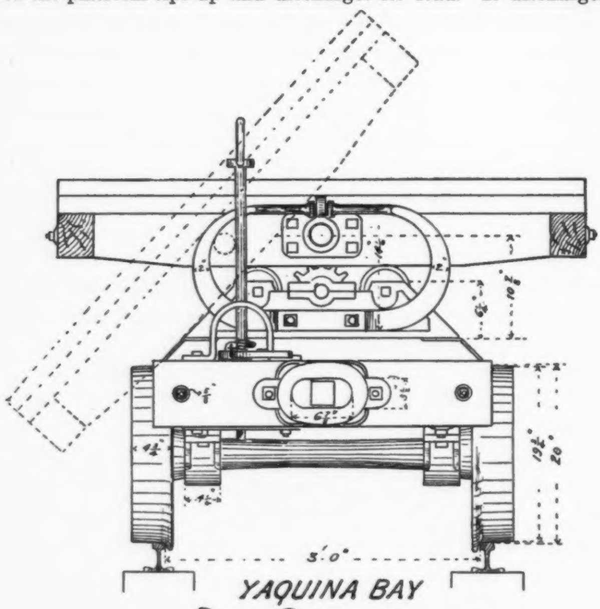
This method was necessarily slow and expensive, and attended with some loss, for, in a number of instances, before the new bents could be well secured with rock, storms came up and carried them away. During one storm, six bents were carried away.

On the south jetty, the brush mattress work immediately followed the tramway construction. The mattresses were constructed beneath the tracks, and about the piles upon poles supported by ropes from the tramway timbers. These mattresses were of brush fascines and poles bound firmly together. When a convenient length was completed, it was loaded with stone and lowered to the bottom. Side mattresses were also constructed where deemed necessary. An ingenious mattress car, to facilitate handling these side mattresses, was designed for and used on the Columbia River Jetty; this has been adopted for the Coos Bay work, but was not used at Yaquina.

The stone used in the jetties is a moderately hard sandstone, quarried from bluffs along the Yaquina River, about 14 miles from the entrance. In weight the pieces vary from 8 tons down to a few pounds. The average weight has constantly increased since the commencement of jetty construction, and now probably two-thirds of the amount aver-

ages 4 tons to the block. The stone is loaded by derricks directly from the quarry upon barges, 90 x 27 x 5 ft. depth, carrying about 250 tons. These barges are towed to a receiving wharf, where they are unloaded upon cars which are run out upon the jetty and dumped.

The cars are of 3 ft. gauge and 5 ft. wheel-base. The car platform is 8 ft. long and 5 ft. wide, and it is mounted upon rollers which permit it to move sideways, so as to bring the center of gravity past the rollers, when the platform tips up and discharges its load. It discharges in



either direction. The side motion is given to the platform by means of a rack and pinion. After discharging its load, the platform is easily righted, and is locked by a ring fitting over a projecting pin. In dumping, this projecting pin limits the side movement of the platform by working in an oval ring. The drawing on this page is an end view of the car. In some cars recently constructed the construction was modified by making the limiting oval smaller and placing it beneath the platform instead of at the ends.

Cost of the Work.—The total amount which has been appropriated for the work is $635 000, extending over the period since June, 1880. This will nearly complete the work. The total length of the two jetties, including the necessary shore protection at their roots, is: north jetty, 2 700 ft.; south jetty, 4 300 ft.; total, 7 000 ft. This makes the average cost of the jetties $90 per linear foot.

The work has been done by hired labor, with plant purchased from the appropriations and owned by the Government, and which is in good shape and suitable for similar work elsewhere.

The cost of the various items entering into the work has varied greatly. During the past year, the cost of the stone dumped in the jetty has been 82 cents per ton of 2 000 lbs. This is the least that it has ever cost on this work. Piles have cost from 7 to 9 cents per foot, and lumber, $10 to $12 per thousand. The cost of the double track tramway on the north side, where piles could be driven to a good holding, was $4.76 per foot; the cost per foot of that portion where piles could not be driven was $8.54.

The construction of the jetties gradually changed existing conditions inside of the harbor, and caused sand to accumulate in front of the first wharf built on the south side, necessitating the building of a second; changes continued, and a third had to be built. Two years ago this also was shut off, and it then became necessary to extend a single track tramway back to a new wharf 3 500 ft. from the old third wharf. These changes in wharves added largely to the cost of the work.

History of the Plan of the Work.—The plan of the work as finally adopted, and which is now very nearly completed, was not matured at the time work started. In fact, the plan has grown with the work.

The first work proposed and started was the protection of the south spit against erosion, and the building of a short half-tide crib-work and stone jetty, from the south spit, to keep the channel from taking its southern and most dangerous position, and to direct the waters into a central channel, where it was hoped to get a low-water depth of 10 ft. It was found impracticable to use cribs to advantage, and the plan was changed to that hitherto outlined—a brush mattress and stone construction built from a pile tramway; this was in 1882. After the work had been extended out about 2 000 ft., lack of appropriations compelled a cessation of work. In 1884, when work was resumed, it was found that the small piles hitherto used were in such bad condition that a

new tramway, built of larger piles, and with the top at a higher level above the water, was necessary. In 1886 the project was enlarged by providing for an extension of the mid-tide south jetty, 1 700 ft., and the construction of a mid-tide north jetty, about on the lines as shown on Plate XVIII. In 1888 this was changed by providing for the elevation of the south jetty to full high tide, and again in 1892 it was decided to raise the north jetty to full high tide.

Results of the Work.—The primary result of the work has been to double the low-water depth on the bar at the entrance to Yaquina Bay and to maintain the bar channel in a permanent and good location. As before stated, the original ordinary depth on the bar was 7 ft. at low water, and the channel was anywhere within a sector of 120°. Now, there is, and has been for a year past, a least depth of 14 to 15 ft. upon the bar. This has at times increased to 18 ft.; this depth, with an ordinary tide of 7 ft., gives 21 ft. least depth at the entrance. Behind the jetties, that is, on the side away from the channel, great quantities of sand have accumulated. Computations show that on the south side this accumulation amounts to fully 2 000 000 cu. yds., while on the north side it is about 100 000 cu. yds. This brings into prominence a second function of the jetties, which is to form reservoirs where the drifting, moving sands, hitherto forming the bar, can accumulate. These sands are thus not only removed from their mischief-making location, but, by forming in and behind the jetties, strengthen the weak rubble mounds and permit a reasonable hope for permanent endurance to structures, which, without this accretion, would certainly be far less permanent. The sands behind the jetties protect them against waves and seas coming up or down the coast, and, by furnishing a solid backing, enable them to resist better the channel waves. These sands, forming in front of the sandy cliffs to the north and south of the jetties, shield these cliffs to a greater or less extent for considerable distances against the waves, and thus tend to limit erosion and the production of sand in the vicinity of the harbor.

The results of a permanent increase of depth and fixed direction of the bar channel only came when the two jetties were nearing completion. The south jetty alone prevented the channel from occupying its bad southern position, but it still roamed over a considerable sector and was driven hither and thither by the ocean currents and waves. At times a heavy deposit of sand would form on the channel

side of the south jetty, throwing the channel to the north and making it shallow and crooked. The tendency to do this lessened as the north jetty was extended, and now it has practically disappeared.

The work remaining to be done at Yaquina is to increase the en- rockment of both the north and south jetties, so that when final settle- ment takes place it will be to full high water throughout their length. It is also designed to put a few short groins out on the channel side of the south jetty before it is finally left, as a safeguard against undermining. It is hoped that the final result of the jetties will be to increase still further and permanently the depth on the bar to a depth at the mean of the lower low waters of 18 ft.

Jetty at Mouth of the Columbia River.—This great work is now prac- tically completed in general accordance with the plan adopted in 1884.

The Columbia River, ever since its discovery in 1792, has been the chief harbor of the Pacific Northwest. But the shifting character and variable depth of the bar channels ever caused its entrance to be held in terror by mariners and ship-owners. The work done has now changed all this; the entrance to the river is robbed of its terrors, and is as safe as any harbor could be made upon this stormy coast. The largest vessels now sail in and out without difficulty.

The Columbia enters the Pacific Ocean between Cape Disappoint- ment and Point Adams. The former is a rocky headland about 200 ft. high, and the latter, a low changeable sandy point 6 miles distant, in a south-easterly direction. Taking this line of 6 miles as part of a chord, the bar extended out convexly towards the sea, and its vertex was about 4 miles outside of the chord. Inside the headlands there existed shoals and sand islands, dividing the river, and outside, there were great areas on which the seas constantly broke. Through these shoals and islands the entrance channel ran with depths on the bar varying from 19 to 27 ft.

Eleven surveys of the entrance were made from 1792 to 1881, which showed a great variety of conditions. The best water known for cer- tain was 26 to 27 ft. in 1868, and for a short time thereafter. The usual ordinary depth on the bar was about 22 ft. The estimated mean tidal ebb discharge of the Columbia is 1 000 000 cu. ft. per second. The river has a fresh-water discharge at low water of about 90 000 cu. ft. per second, and at high water of about 600 000 to 700 000 cu. ft. per second.

In fixing upon a plan of improvement, it was found that the best natural condition existed when Clatsop Spit was raised well above low water, and extended for more than 2 miles from Point Adams in a north-westerly direction towards the bar. This, and all other considerations, indicated that the best method of improving the entrance was by building a jetty, starting at Point Adams and extending in a north-westerly direction to a point about 3 miles south of Cape Disappointment, the jetty to stop short of this point, or extend beyond it, as experience might indicate to be necessary. The object of the work was, in brief, to concentrate the river within moderate width, and to discharge it as a unit to the sea. The jetty was to be a rubble mound, built on brush fascine mattresses, 3 ft. thick and about 40 ft. wide, and to be brought up to low water. This is the work which is now about completed.

The total length of the jetty, as constructed from the receiving wharf, is 4¾ miles, of which 4¼ miles are of the jetty proper, and one-half mile is the approach to the wharf. This is believed to be by far the longest jetty ever built in the world. The method of construction has been the same as that previously described at Yaquina Bay, but with important modifications, necessitated by the greater magnitude of the work.

The tramway is nearly the same as that at Yaquina, being a double track, 3-ft. gauge railway, on pile bents spaced 16 ft. apart and 24 ft. above low tide. The tracks are 13 ft. between centers. The pile-driver used in this work is a much more powerful and effective machine than the one used at Yaquina, and capable of extending the tramway 4 or 5 bents in a day. In connection with the driver is a tender car, running on the two tracks, and carrying a day's supplies of piles, lumber, rails, etc. The mattress work is essentially the same as that at Yaquina. The stone used is a tough, hard, heavy basalt, which is quarried on the Columbia and Willamette rivers, above the mouth of the latter, and taken to the work on model barges, each carrying about 400 tons.

Plate XIX illustrates the jetty cross-section, tramway and mattress work.

The work at the Columbia River has been done by hired labor, with plant purchased and owned by the Government, but most of the material entering in the construction has been purchased by contract. The old military post of Fort Stevens, with all its buildings, was turned over to the Engineer Department for its use during the

PLATE XIX.
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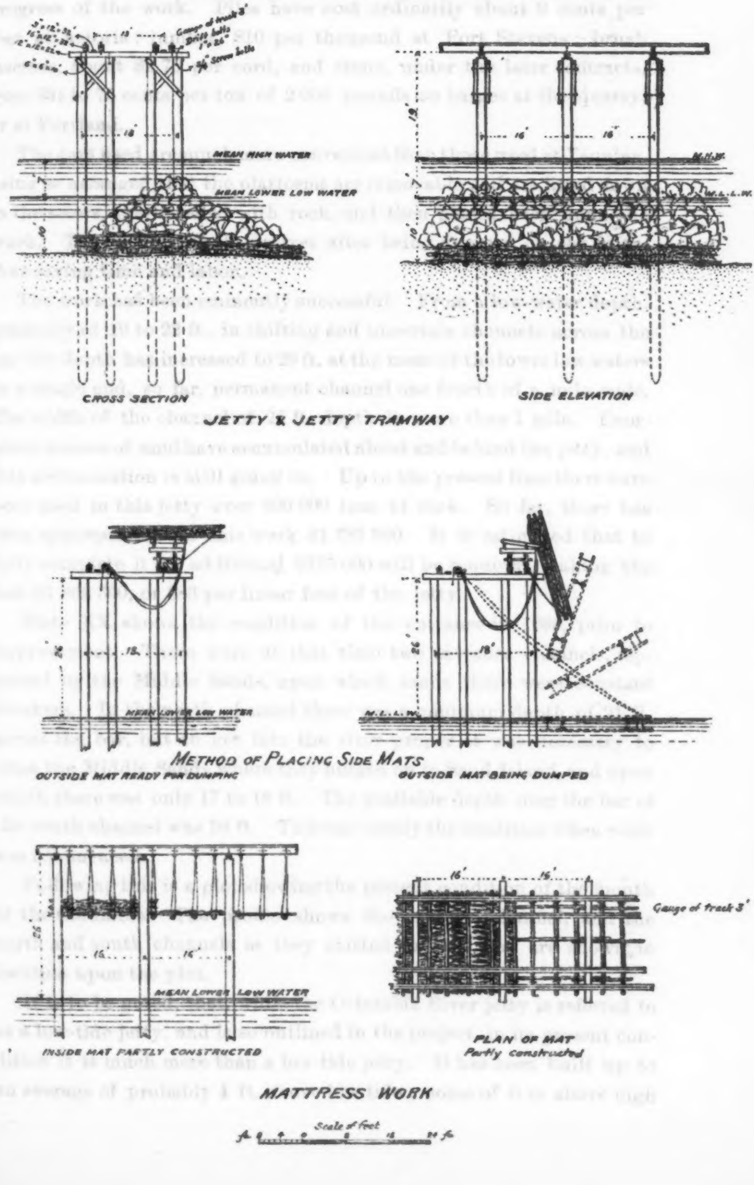
IMPROVEMENT OF THE MOUTH OF THE COLUMBIA RIVER, OREGON.



progress of the work. Piles have cost ordinarily about 9 cents per foot at Astoria; lumber, $10 per thousand at Fort Stevens; brush fascines, about $2.75 per cord, and stone, under the later contracts, from 63½ to 75 cents per ton of 2 000 pounds on barges at the quarry, or at Portland.

The cars used are much more convenient than those used at Yaquina, being so arranged that the platforms are removable and are lifted down to the scows, there loaded with rock, and then placed back upon the truck. They also right themselves after being dumped on the jetty, thus saving time and labor.

The work has been eminently successful. From a low-water depth, generally of 19 to 22 ft., in shifting and uncertain channels across the bar the depth has increased to 29 ft. at the mean of the lower low waters in a single and, so far, permanent channel one-fourth of a mile wide. The width of the channel of 27 ft. depth is more than 1 mile. Enormous masses of sand have accumulated about and behind the jetty, and this accumulation is still going on. Up to the present time there have been used in this jetty over 600 000 tons of rock. So far, there has been appropriated for this work $1 687 500. It is estimated that to fully complete it an additional $175 000 will be required, making the cost $1 862 500, or $83 per linear foot of the jetty.

Plate XX shows the condition of the entrance in 1880, prior to improvement. There were at that time two entrance channels, separated by the Middle Sands, upon which sands there were constant breakers. In the north channel there was a minimum depth of 21 ft. across the bar, but to get into the river proper it was necessary to cross the Middle Sands where they hinged on to Sand Island, and upon which there was only 17 to 18 ft. The available depth over the bar of the south channel was 19 ft. This was nearly the condition when work was commenced.

Following this is a plot showing the present condition of the mouth of the Columbia. The profile shows the existing channel, and the north and south channels as they existed in 1880, and are shown in location upon the plot.

It is to be noted, that, while the Columbia River jetty is referred to as a low-tide jetty, and is so outlined in the project, in its present condition it is much more than a low-tide jetty. It has been built up to an average of probably 4 ft. above low tide; some of it is above high

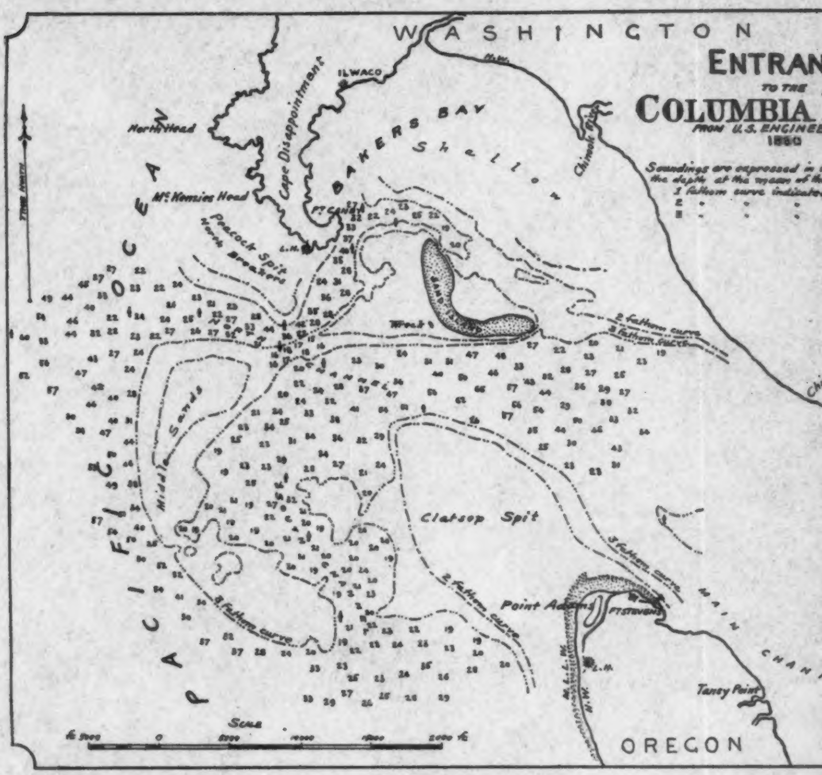
water. It has been raised above low water with the object in view of providing for subsidence to low water when a condition of stable equilibrium is reached. Also, it was found that in places there was a decidedly strong tendency at the higher stages of the ebb tide to break across the jetty and develop a channel across the sands. To counteract this tendency, the jetty was strengthened and raised at those places.

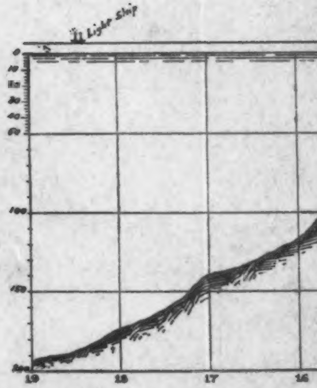
Wilmington Harbor, California.—The first attempt at improving a harbor entrance on the Pacific Coast was at Wilmington, California, and it is believed that nowhere in the world has there been a more successful work of harbor improvement, or one where the proportional increase of depth obtained has been greater than at this point.

Wilmington Harbor is an estuary, connecting with San Pedro Bay in north latitude 33° 45′. It is the only land-locked harbor between San Francisco and San Diego. Its tidal area is about 1 400 acres, much of which is sand flats well above low water. The mean range of tide is 4 ft., and the average mean tidal discharge is about 6 000 cu. ft. per second. In its natural condition, there existed a bar at the entrance to the harbor, with from 1 to 2 ft. of water at low tide. For many years, this harbor, poor as it was, furnished the outlet for the magnificent country about Los Angeles, which city is only 20 miles from it. San Pedro Bay, in which the depth of water varies from 4 to 9 fathoms, furnished anchorage to vessels loading and unloading, and connection was made between the harbor and anchored vessels by a system of lighterage. It was to do away with this expensive system of lighterage, and to enable the ordinary types of coasting vessels to enter and leave the harbor, that its improvement was undertaken.

On Plate XXI is shown the condition of the entrance to the harbor before any works of improvement were undertaken. Above Rattlesnake Island the estuary widens out, and is separated from San Pedro Bay by this Rattlesnake Island, and a large area of low-lying flat lands, often covered at high water. Rattlesnake Island is a narrow strip of grass-covered sand dunes, rising 8 to 10 ft. above high water. After passing the lower end of Rattlesnake Island, the channel was held by an accumulation of sand to a contracted and good depth for a distance of 4 000 ft. Then it spread out into a shallow bay on both sides of Deadman's Island.

The plan of improvement entered upon in 1871 was to connect the

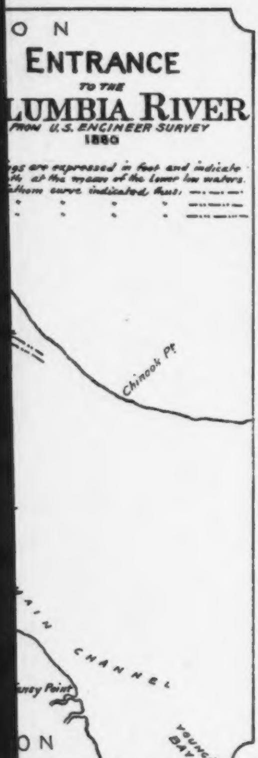




PROFILE OF COLUMBIA RIVER CHANNEL, FROM ASTORIA TO THE SEA

ALSO SHOWING PROFILE OF NORTH & SOUTH CHANNELS IN 1880

Horizontal Scale in Statute Miles
Vertical Scale in feet


O N
ENTRANCE
TO THE
LUMBIA RIVER
FROM U.S. ENGINEER SURVEY
1880
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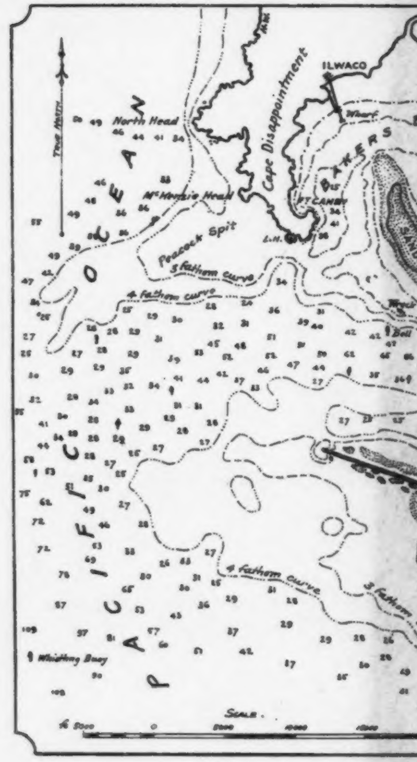
Chinook Pt
CHANNEL
Youngs Bay
ON


True North
North Head
McKenzie Head
Cape Disappointment
ILWACO
Wharf
BAKERS
FT. CANBY
L.H.
Peacock Spit
3 fathom curve
4 fathom curve
OCEAN
PACIFIC
Bell
Whistling Buoy
SCALE.

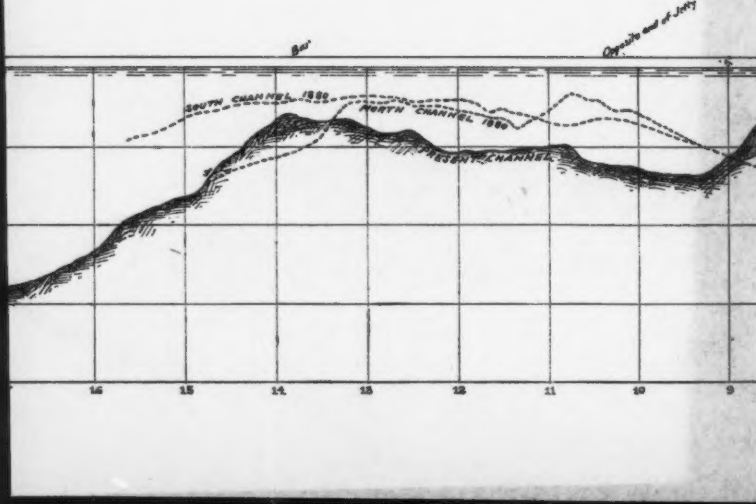

Bar
Opposite end of Jetty
SOUTH CHANNEL 1880
NORTH CHANNEL 1880
PRESENT CHANNEL
16
15
14
13
12
11
10
9

PLATE XX.
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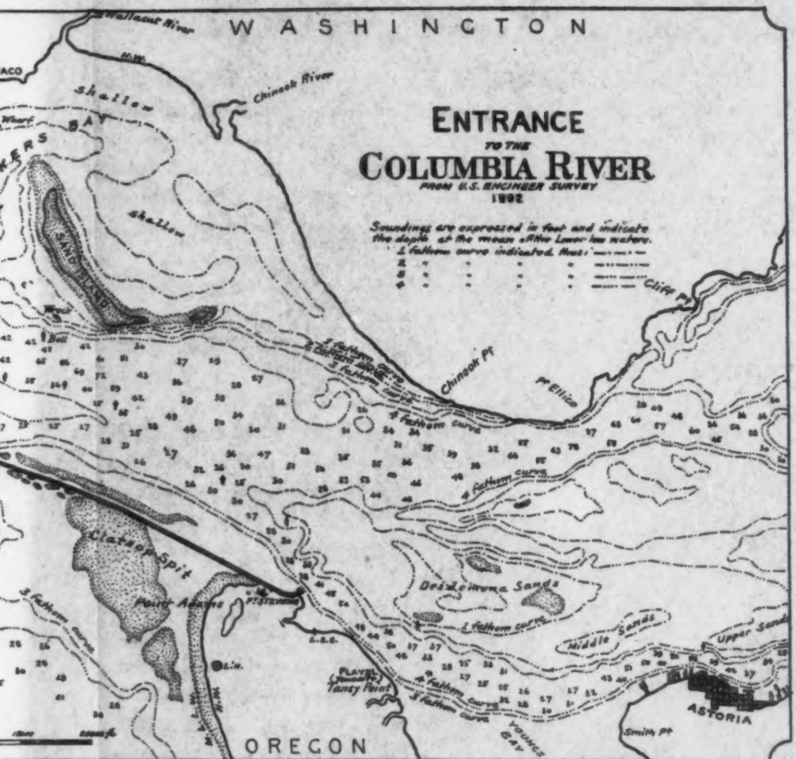

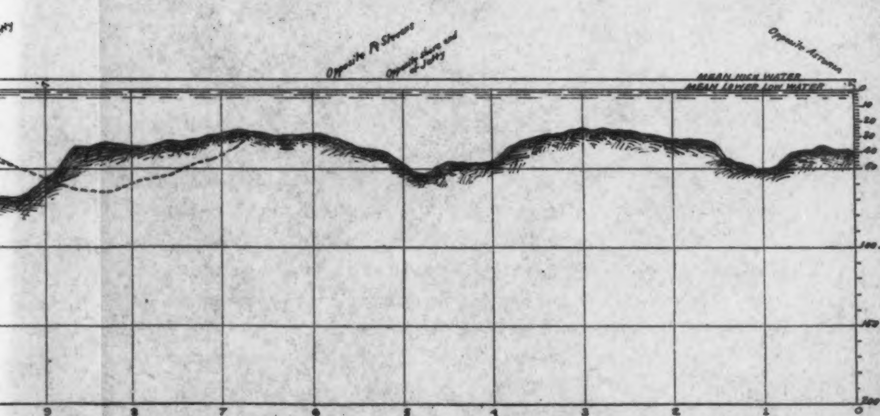

lower end of Rattlesnake Island with Deadman's Island, so as to confine the channel and make it connect with the deeper waters of San Pedro Bay to the west of Deadman's Island, and to do such work of dredging as might be found necessary. This plan has been carried out, and is now completed as shown by the plot (Plate XXI) exhibiting the entrance in its improved condition.

Besides this work, a second jetty has been built extending out from the main shore to the channel, then parallel with it, past Deadman's Island. Also, in the prosecution of the work, it was found that in the line of the desired channel there was a reef of clay and stone which did not readily scour, and this rendered necessary a large amount of dredging.

The method adopted for accomplishing the desired end at Wilmington varies much from the methods at other points, and this arises largely from the fact that all stone and timber had to be brought from points outside the harbor. It was proposed to connect Rattlesnake and Deadman's Islands with a simple structure, composed principally of piling. This structure was not intended to have any great degree of permanency, but simply by its presence to bring about and determine an accumulation of sand dunes similar to Rattlesnake Island, which should form the real channel contraction works.

The first adopted project of 1871 aimed at getting a low-water depth at the entrance to the harbor of 10 ft. The work was commenced in 1872, and the connection of the two islands was completed in 1874.

The length of this jetty, or training wall, is 6 700 ft. The first section of 3 700 ft. next Rattlesnake Island consisted of a line of double sheeting piles, substantially braced, and rising to about a foot above high water. The next 1 000 ft. consisted of two parallel rows of 12-in. piles, 10 ft. apart, the piles in each row being driven in juxtaposition, and strongly braced and partially filled with brush, sand, gravel and stone. The section of 2 000 ft. next Deadman's Island is a rubble mound.

Various vicissitudes were met with in the conduct of the work. It was found that the sand did not accumulate as rapidly as wished or expected along and behind the line of the jetty. It was attempted to expedite this accumulation by encouraging plant growth, and by the use of brush fences, and by building groins. The non-accumulation of sand in the places desired exposed the work, without its hoped-for

backing, to undermining and settlement, and the timber work, for longer periods than expected, to the destructive action of the teredo.

It became necessary to strengthen the pile work by the addition of stone and gravel. Between Deadman's Island and the main shore it was found that the bottom was of such a nature that dredging was required, and a channel was dredged across it. Stone jetties were built out from the main work to contract the width of the channel, and control the action of the current.

In the year 1881, the desired object of obtaining a depth of 10 ft. at low water had been more than accomplished. The two jetties had been extended to Deadman's Island; a channel 12 ft. deep and 235 ft. wide had been dredged through the reef at the island, and there was rather more than 10 ft. depth at low water at the entrance.

But the interests of commerce continued to demand further improvement, and a project was adopted that year, having in view the securing of a permanent low-water depth at the entrance of 16 ft. This project consisted of the strengthening of the existing works, the dredging of a channel 400 ft. wide and 16 ft. deep across the reef at Deadman's Island, and the completion of the west jetty and the extension of the east jetty, beyond Deadman's Island, if found necessary, to a depth of 18 ft. of water.

The desired object has been very nearly attained. There is a through inner channel of not less than 16 ft. over a width of 300 ft. through the channel at Deadman's Island, with a bar channel at the entrance of 14 ft. depth and 200 ft. width. It is expected that, when the west jetty is extended south from Deadman's Island, the point of the bar shown will be cut off and the full depth of 16 ft. at the entrance realized.

While the general plan of this work as constructed is about the same as that originally adopted, yet many changes were made in the various features and details of it, which were found to be necessary as the work progressed. It was found necessary to excavate many thousands of yards of clay and stone not included in the original design. The history of this work emphasizes, in a marked manner, that the improvement of harbors of this class is best made successful by a study of the actions and tendencies of the currents as they are determined by the constructions which are made to control them. These actions can seldom be fully understood, and their directions recognized in advance;

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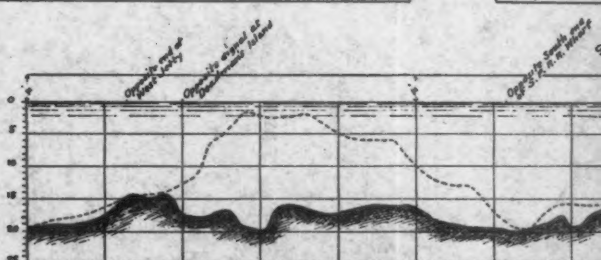

PROFILE OF WILMINGTON HARBOR SHOWING PRESENT AND

Present bottom of Channel indicated thus: Bottom of Channel preced

Horizontal and Vertical scales in feet

PLATE XXI.
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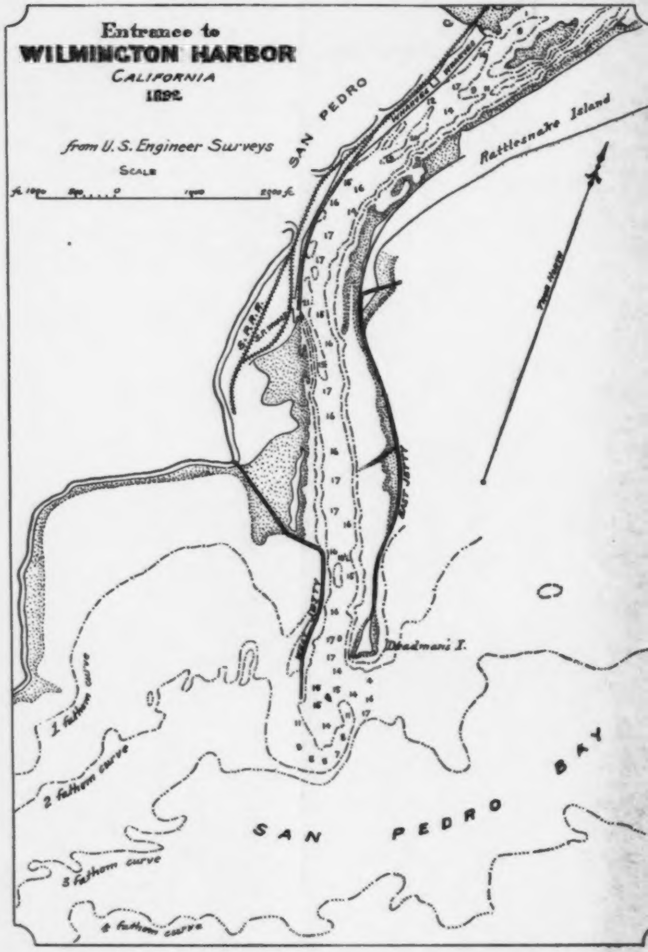

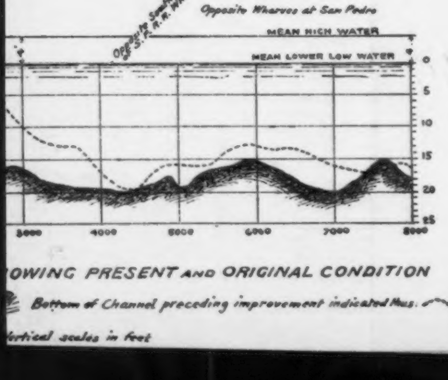

OWING PRESENT AND ORIGINAL CONDITION

Bottom of Channel preceding improvement indicated thus.

Vertical scales in feet

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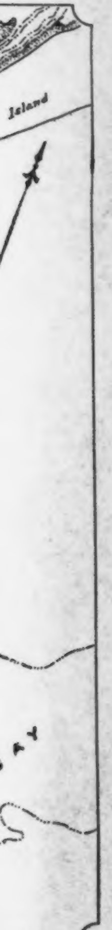

but when recognized, it is generally sound policy to act as far as possible in harmony with them, and plans should admit of alterations as found necessary.

Nearly all the pile work at Wilmington was done by hired labor after the failure of contractors to carry out their agreements. The method of construction was as follows:

Six steam pile-drivers were used. The foremost driver was arranged to reach out 10 ft. in front of the work; it drove the scaffold piles, which were 10 ft. apart, in pairs. Upon these, stringers were placed, and these were crossed by other timbers at right angles, forming a platform 30 ft. wide, upon which the drivers were worked. The second driver drove the brace piles 5 ft. apart at an inclination of 30° to the vertical. The third driver drove the upright piles 5 ft. apart, and the fourth and fifth drivers drove the sheeting piles. Driver No. 6 worked as opportunity offered, and followed in the rear, taking up the scaffolding as the work was finished. The driving was done by an ordinary hammer, and the difference between this method of driving and the hydraulic method now used is shown by the fact that in some cases it took 350 blows from a 2 400-lb. hammer to drive a pile 17 ft. into the sand. At Coos Bay the average penetration is 27 ft. into similar sand, and this is reached in a very few moments after the pile is in place and the pump started.

The stone used in this work has been mainly brought from Santa Catalina Island, which lies about 20 miles directly off shore; some stone was taken from Deadman's Island, and some of the material excavated from the channel was used on the jetties. This stone was all deposited directly from the barges and scows without the intervention of a tramway or cars.

Starting out in the prosecution of this work with the idea and hope that the wooden-pile tramway wall would cause an accumulation of sand as an extension of Rattlesnake Island, which would effectually contract the channel and guide the current, it was found, as the work progressed, that this hope was not realized in fact, and the work, as now completed, is principally a rubble mound built up to about 6 ft. above high-water level.

The southerly portion of the single pile work along which Rattlesnake Island has been extended has been raised to about 2 ft. above high water, so as to prevent the sand from drifting over the bank into

the harbor. It is found, generally, that, as this work is raised, the tendency of the sand beach is to extend seaward.

The total amount which has been appropriated for this work is \$904 000, and it is estimated that \$51 000 will be required to complete it. It is to be noted that about half the money appropriated had to be discounted from 10 to 30% on account of the disparity between gold and greenbacks on the Pacific Coast.

The results secured at Wilmington are not due entirely to the jetties which have been built. Besides the reef of rock and clay which was removed, a large quantity of sand has been removed from the channel by dredging. The necessity for this arose from the fact that the channel debouches into the shallow waters of San Pedro Bay, and it was feared that if the ebb current was allowed to do all the work of scouring out the channel, it would carry out the material and deposit it on a bar in front of the entrance, and thus defeat the object of the work. So it was decided to remove a large part of this material by dredging, while the scouring action was being increased by strengthening, raising and extending the jetties.

It is believed that the results obtained at Wilmington are largely due to the protection afforded by Santa Catalina Island, which lies 20 miles away in a south-westerly direction. This island is 21 miles long, and is directly in the line of approach to the harbor of the most severe storms which prevail along the coast. It is the opinion of those most familiar with the work that without this island it would be impossible to maintain the entrance at anything like its present navigable capacity.

Other Jetty Harbors.—Besides the three places previously mentioned, where the jetties are practically completed and the results of their action known, jetties are in course of construction at Humboldt Bay, California, and Coos Bay, and the mouths of the Coquille and Siuslaw Rivers, Oregon. At none of these places is the work near completion. At each of them the projects consist of two jetties of brush mattresses and rubble, built up to full high tide.

Humboldt Bay.—At Humboldt Bay the work already done consists of shore protection and the building of the south jetty to a length of 3 033 ft., all of which, however, is not yet completed. The north jetty is to be 6 750 ft. long, and the south jetty 7 800 ft. long.

The work so far done has been from a single-track standard-gauge

PLATE XXII.
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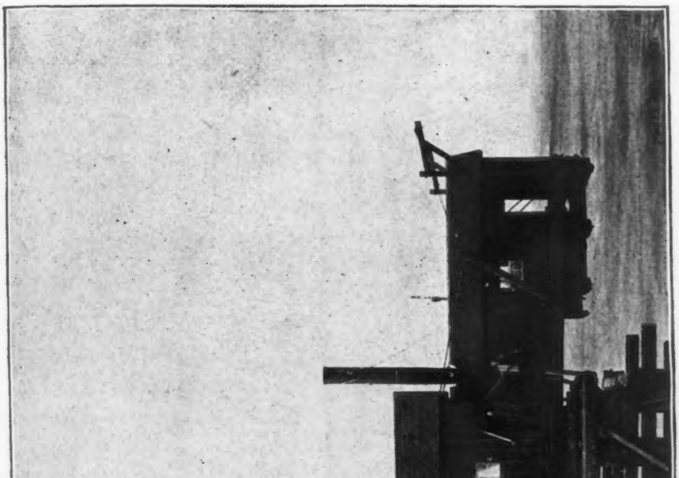

pile-bent tramway, similar in other respects to the tramway at Yaquina Bay. There is no stone available directly from the navigable waters of Humboldt Bay, and it has to be brought by rail, which adds greatly to the cost of the work.

Coos Bay.—At Coos Bay, the north jetty is projected to be 9 600 ft. long, and the south jetty, 4 200 ft. long, both to be high-tide jetties. The north jetty tramway and mattress work has been built to a length at present of 6 700 ft., and the enrockment has been brought up to high water for 4 800 ft. The work is being done very cheaply, as the following prices will indicate. Lumber is bought for $8 per thousand; piles of the best quality of red and yellow fir, for 3 cents per foot; brush fascines, for $1.75 to $2 per cord, and stone is delivered at the receiving wharf on barges at 53½ cents per ton of 2 000 lbs. The work here is modeled closely upon that at the Columbia River. The pile-driver used is one which was formerly used at the Columbia River (see Plate XXII). The cars are the same as the Columbia River cars, and were made at the machine-shop established in connection with that work. Plate XXIII illustrates the car and the method of loading. A number of extra platforms are provided, all of which are interchangeable. The car body to which the platform is temporarily attached when loaded is hung on trunions, and the combination is so arranged that, when loaded, the center of gravity is above the trunions, which renders it easy, by means of the gearing, for one man to dump the load. When the load is off, the center of gravity is below the trunions, and the body and platform return by the force of gravity to the horizontal normal position. Plate XXIV shows a loaded train of cars upon the tramway. Upon this picture is shown a center mat ready for lowering.

Coquille River.—The work at the mouth of the Coquille River differs from that at any other point along the coast in that the pile tramway is made of two rows of piles driven as close together as possible. These rows are 8 ft. apart and are surmounted by a single-track 3-ft. gauge railway. From this track stone is dumped between and on the outside of the rows. This construction was adopted for several reasons. First, on account of the danger of an open-work pile tramway being injured or destroyed by drift timber which comes down the Coquille in exceptionally large quantities; second, the low price of piling, and third, in order to get beneficial results as quickly as possible.

Plate XVII shows the Coquille River entrance at low water, and gives a general view of the jetties as at present constructed. This plate shows a typical view along the Oregon coast, and illustrates the drift-wood as previously mentioned.

Siuslaw River.—At the mouth of the Siuslaw the work is still in its preparatory stages.

General Considerations.

These three works, at Yaquina, the Columbia River and Wilmington, are now practically completed according to their adopted designs, and the results desired have been accomplished. But what of their future? They have been built in the most economical manner with the materials available, and those having them in charge have reasonable hopes and confidence in their stability and the permanence of the results obtained. There are many things that may happen to cause these hopes and confidences to be realized, and others, to blast them. There are questions which can only be determined by time and the elements. There are a number of features which are open to discussion, and which are briefly alluded to in what follows.

Height of Jetties.—There are, and have been, differences of opinion in regard to the proper elevation to be given the jetties. The Columbia River jetty is designed to be a low-tide jetty under the existing project, in conformity with which work is progressing. As a matter of fact, however, it is, at least, a mid-tide jetty in its present condition, and the results which have been accomplished in the improvement of the entrance have been brought about, not by a low-tide jetty, but by a jetty built up to at least half tide, and with some portions above high tide.

Both jetties at Yaquina Bay were originally designed as half-tide jetties, but both have been raised in part, and are being entirely raised to well above full high tide.

The Wilmington jetties are built to about 6 ft. above high tide.

The works at Humboldt and Coos Bays, and the Coquille and Siuslaw Rivers, are designed to be high-tide jetties.

The advantages of low jetties, are, first, economy in construction; second, that they are supposed to permit a freer entrance to the flood tides and a more complete filling of the tidal compartment; and third, that they are less exposed to the action of the waves and consequent

PLATE XXIII.
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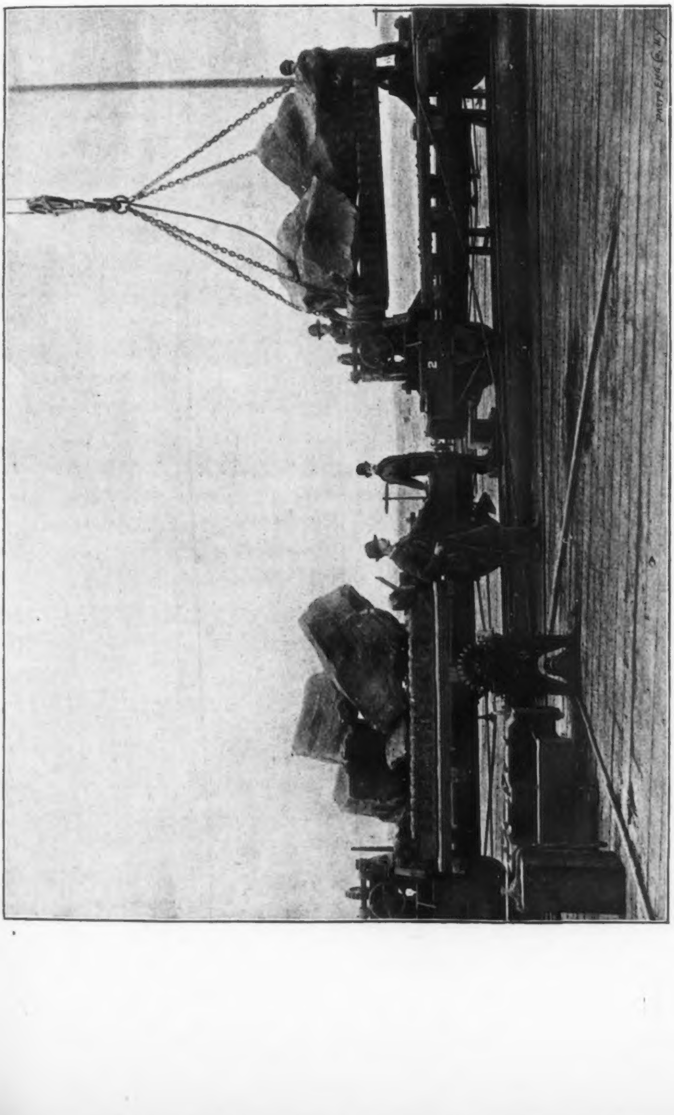

deterioration. In regard to these advantages, it may be stated that the differences in first cost between a low, mid, or high tide jetty, constructed in the way the Pacific Coast jetties have been, is not very great. For either, the same plant, in wharves, boats, scows, tramway, pile-drivers, locomotives, cars, mattress foundation, etc., is required. The difference is simply the cost of an additional amount of rock to raise the work 3, 6 or 7 ft. higher, as the case may be. Ordinarily this additional amount will form but a small proportion of the cost of a high-tide jetty.

In regard to the second advantage of permitting the freer entrance to the flood waters, this might be a good point if the bottom of the entrance were unyielding and remained the same as before the works were built. But within the limits of scour, the beds at both Yaquina and the Columbia, are of easily moved sand, and any reasonable decrease in width would readily be made up by increased depth. The same is true of all other points along the coast where work is in progress, except Wilmington.

Unless it should be endeavored to choke down an entrance to an abnormal degree, the advantages of the lower type of jetties in permitting a freer inflow of the tides are more fanciful than real.

In regard to exposure, it is unquestionably true that a high-tide jetty is more liable to injury and beating down by heavy seas than one built only to low tide. But this liability is much reduced from the protection given to the jetties by the outlying sands, upon which the strong seas break before reaching the works; and because, with the present facilities at most of the places where work is now in progress, stone of large size, 5 to 8 tons in weight and even larger, can be readily had to top out the jetties.

On the other hand, the advantages of high-tide jetties over those lower are that they more perfectly control the tidal currents, compelling a deeper scour with jetties equally far apart, or an equal scour in an entrance of greater width.

High-tide jetties have also a distinct advantage over low-tide jetties in counteracting a tendency which may exist from one cause or another to cut through the jetty and develop a channel across it. This was evidenced in the construction of the Columbia River jetty. In former years, there existed quite close to Point Adams an outlet channel known as Tillamook Channel, which carried much water. The jetty

crosses the location of this old channel. The building out of the jetty, and, perhaps, other causes, have developed a strong tendency on the part of the waters to flow out this way again. To counteract this tendency, the jetty at this place had to be built high and wide. If it had been left at low tide, the great volume of water crossing it would have scoured a deep channel across the sands and undermined and torn down the jetty. The building of it up to high water has effectually prevented the development of the channel.

The effective scouring force of an ebb current flowing out between high-tide jetties would be enormously reduced if the jetties should be dropped to low water. It is not far out of the way to state that the reduction would be at least one-half as a general rule. On the Pacific Coast, also, high-tide jetties are more efficient than low jetties in their secondary function of impounding sand. The more of the moving sand that can be kept out of circulation the better, and hence this is considered an important advantage. At all points, a very liberal amount of stone is placed upon the jetties, bringing them up considerably above what they are designed to be, to allow for settlement.

It is expected that the jetties at Yaquina will cause the deepening of the bar channel to a still greater extent than that at present existing, after they have been entirely completed and in full operation for a longer period. And it is hoped that the combination of jetties, outlying reef, and prevailing winds and currents will keep the sands from accumulating in front of the jetties and from forming a bar through which the ebb currents will be unable to keep a good channel permanently scoured out. This latter feature of the case is fraught with some uncertainty, however, and in the future it may be necessary to extend the jetties.

At the Columbia, the entrance width between the end of the jetty and Cape Disappointment is 3 miles. It is by no means certain that the jetty, as now practically completed, will be able, with this width, to maintain permanently the depth already secured upon the bar.

The jetty, in its present condition, is fully a mid-tide jetty. In this condition, it has succeeded in developing a bar channel with practically 30 ft. of water, the depth aimed at by the project. It has done no more than this. If the jetty had been built simply to low water, and the scouring force upon the bar thus greatly diminished, it may be considered as certain that this depth would not have been attained. And

PLATE XXIV.
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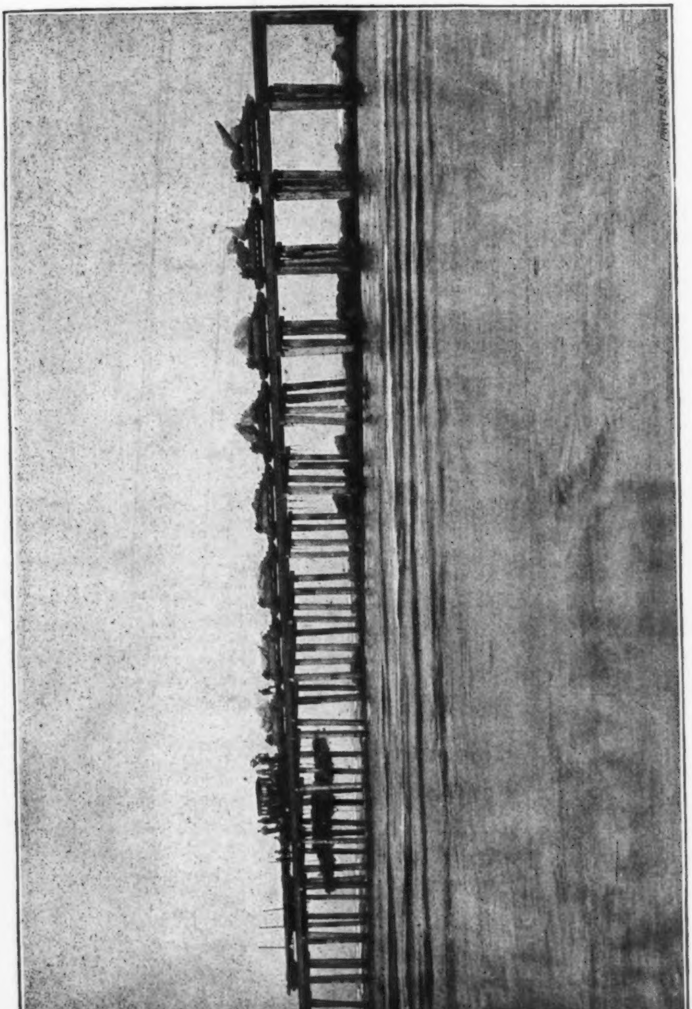

if, in the future, the jetty should settle to low tide, it is reasonable to believe that the existing channel will not be maintained. These considerations point to the desirability of leaving the jetty, when it is finally completed, in such a condition that, when the enrockment has fully settled into place, it will furnish as great a directrix to the waters as it does at present. The additional cost of adding sufficient stone to accomplish the end outlined above will be small compared with the money already expended. It may also be necessary, at some time in the future, to extend the present jetty or to build out a second one from Cape Disappointment along Peacock Spit, or to do both, although there is very little probability that either will be necessary.

It is excusable for all concerned in it and benefited by it, to be enthusiastic over the results obtained by this great work, which has been built at about half the originally estimated cost.

Deterioration of the jetties themselves may be brought about by a number of causes, as abrasion and disintegration of the stone, settlement into the sand, beating down by the waves and undermining by racing currents.

At the Columbia, the rock used is a hard, heavy basalt, the abrasion of which is very slight. At Yaquina and other points along the coast, however, the only rock available is sandstone of variable quality, which is more easily abraded. It is endeavored to reduce this abrasion to a minimum by putting the hardest, largest and heaviest rock in the more exposed situations, and by using it with a lavish hand.

It is found that this sandstone has very much greater endurance when constantly wet than when exposed to the air, that the interstices in the enrockment become filled with sand, and that the rock soon becomes covered with barnacles, all of which tend to preserve it from abrasion. Sandstone is the material which is generally available and generally used along the coast for jetty work.

At Yaquina, the north jetty being built upon a rock foundation, it cannot settle into its bed. The south jetty is, however, built upon sand, upon a mattress foundation. Three years ago, this south jetty had been raised to high water, using the least amount of rock possible. During these three years the crest of the enrockment has settled about 2 ft., due to various causes. A large additional amount of rock is being added to put it in as certain a condition of stability as practicable. It is believed that there will be no more deterioration due to

settlement. As far as can be ascertained, there are no indications of settlement into the sand of the Columbia River jetty, and the same is true of the completed Wilmington jetties.

As previously stated, the jetties at Yaquina are protected, to a great extent, by the outlying reef; and at Wilmington, by Santa Catalina Island, as well as by the outlying sands and shoals. These limit the action of the seas in beating down the jetty enrockments very much. In direction, the jetties are nearly head-on to the worst storms. The beating down at Yaquina is mostly confined to the ends of the jetties, and here they will be greatly strengthened by enlarging the mound and using the heaviest stones possible. The Columbia River jetty having been kept at a lower elevation, comparatively little disturbance has been caused by the waves.

Just what result time will bring about in regard to beating down the jetty enrockments by the waves can only be surmised. The enrockment is being made now in the most inexpensive way, and if it is beaten down to too great an extent, it will form a base or foundation for blocks of stone or concrete of sufficient size to resist the wave action.

In contemplation, one of the dangers to which the jetties are subjected, is their undermining by strong currents racing along their length or striking them at an angle. It is possible that the south jetty at Yaquina might be undermined if left unprotected by groins, and a part of it be dropped into the channel. There are as yet no serious indications of danger from this source, although the main channel between the jetties runs nearer to the south channel than it did a year ago, due, probably, to the completion of the north jetty. Before the work is finally considered as completed, a few groins, 50 to 100 ft. in length, will be built out into the channel and up to low water, to guard against this possible undermining.

Some groins and spurs have been built at Wilmington, to better control the currents, which cause deposits of sand and prevent undermining, with excellent results. Before the work at the mouth of the Columbia is finally considered as completed, the question of building groins out on the channel side will undoubtedly be considered, although there is at present no indications of their necessity.

On the long line of the Columbia River jetty, the creeping of the rails, due to the loads all being carried in one way, is very consider-

able, and nearly every winter many of the rails have to be taken up and relaid on this account. The rails, exposed as they are to the sea and salt spray, decay very rapidly, the life of a 30-lb. rail being only about three years. Before being laid they are generally well painted, but the protection thus afforded is very limited.

At Humboldt, the work has been done from a single broad-gauge track; at Coquille, from a single narrow-gauge track, while at the Columbia, Yaquina, Coos Bay and the Siuslaw, the tramway has a double narrow-gauge track. The latter is considered by far the preferable construction, on account of the broad base afforded for the pile-driver, and the increased facilities for carrying on the work of mattress making and depositing rock and transporting piles, lumber, etc., to the front.

At Wilmington and the Coquille, considerable dependence was placed upon the close piling to bring about the desired results; but it has been found that this dependence is not justifiable, and it may be stated that in exposed works of this class little dependence should be placed on structures of wood, but that they should be regarded simply as auxiliaries in the construction of the permanent work of stone.

It seems to be impossible to lay down any general rule governing the location and trace of jetties. Local circumstances must ever exercise a controlling influence thereon. The preference of the writer is decidedly in favor of converging as against parallel jetties, for the reasons generally outlined in the description of the Yaquina Bay jetties. It must, however, be acknowledged that there is a liability in some cases, in jetties of the converging type, of an inner bar being formed by the heavy seas coming in at the entrance and piling up the sands in the wider portion of the jetty channel. This is the case at Yaquina Bay, as can be seen by a glance at the map and profile. This inner bar has, however, and it is believed always will have, fully as great a navigable capacity as the bar at the entrance. This possible defect in the converging jetty system is believed to be more than counterbalanced by the defects of the parallel system, among which may be mentioned greater cost, greater liability to undermining from racing currents, lessening of the tidal area, and a greater interference with littoral currents.

The writer was anxious at one point along the coast to adopt a single curved jetty, concave to the channel, instead of a pair of nearly parallel

jetties, with the hope that a good and satisfactory channel would be developed, as along the concave bank of a river. The situation was such that if the results hoped for should not be attained, a second jetty, defining the channel on the other side, could be added without any increase in the cost above that of the parallel jetties. Circumstances, however, prevented the project being carried out, and the value of a single jetty with a curved trace remains undetermined.

In ordinary cases it is planned to extend the jetties out to a depth of water equal to, or slightly greater than, that expected to be developed in the bar channel; but the works built so materially change the condition that it is impossible to tell at first just how far this extension may be found necessary to produce the desired results.

The location of wharves is a matter of serious importance, as the changes produced by the work added to the natural changes may in a short time render a wharf entirely useless. When work was commenced at Yaquina Bay there was a good channel near the South Beach (see Plate XVIII), and wharf No. 1 was located and used for several years. Sand accumulated about it, however, and wharf No. 2 was built, from which in turn we were driven by sand. Wharf No. 3 was then built, but the accumulation of sand soon after closed the south channel entirely, and the new "Receiving Wharf" was built and connected by a single track tramway with the South Beach. The receiving wharf at the mouth of the Columbia has been extended several times owing to the accumulations of sand.

Nearly all of the jetty work on the Pacific Coast has been done with hired labor, with plant owned by the Government, and of materials purchased by contract or in the open market. The peculiarities of the works and circumstances connected with them have rendered this a more advantageous method than to do the entire work by contract. Perhaps similar work might have been more advantageously done by contract along the Atlantic Coast, where there are many experienced contractors and an abundance of plant. But out here, when the works were started, the case was different; there was no plant suitable for carrying on the operations, and no contractors experienced in such work. In fact, the experiences with minor contractors for furnishing rock and other materials, and doing certain portions of the work, were in many instances disastrous—they failing to carry out their contracts, and thus causing delay, trouble and expense.

Besides all this, the work was new and the conditions but imperfectly known, so that it was necessary for those in charge to feel their way, adopt various methods, and modify plans and designs. Added to this was the fact that most of the works are in out-of-the-way places, far removed from commercial centers and were commenced and have been continued with small and inadequate amounts of money appropriated only once in two years, and we have in general the reasons why the system of doing the work by hired labor has been ordinarily adopted.

It is the opinion of the writer that the system of doing the work as it is being done at the mouth of the Columbia, at Yaquina and Coos Bays, and at the Coquille and Siuslaw rivers, is decidedly more advantageous than it would be if carried out at those places by contract, as it has been and is being done at Humboldt Bay. It is more advantageous for the Government because it is not more expensive, and by reason of its flexibility, the work can be more perfectly controlled and greater results can be accomplished. It is certainly also more advantageous to the cause of labor, for men are invariably better treated and their interests more carefully looked after when they are employed directly by the Government than when employed by a contractor.

Experience teaches that, wherever practicable, it is best to build the jetties up gradually from the bottom along a considerable distance, rather than to push the nearly completed jetty to the front. At Coos Bay the tramway is 1 000 ft. or more in advance of the enrockment. The mattress work is pushed on in front of the enrockment, which slowly follows, taking a very gentle incline towards the front. In this way, the desired object to be accomplished by the jetties is brought about by gradual changes in existing conditions. It is found that directly in front of an advancing jetty there is always a scour, and this is more marked as the jetty is pushed more bodily to the front. It is always necessary, however, when work ceases for any length of time, to carry the enrockment to the end for the protection of the tramway. Then when work starts up again, there is in most instances a deep channel or pocket, directly in front, to be crossed.

In some instances, as in building the north jetty at Yaquina, this plan of building up the jetty over a long line, gradually from the bottom, could not be pursued. Here the lack of penetration of the piles compelled the rock work to follow them immediately.

One of the lessons learned in conducting this jetty work, is not to place too great dependence upon results secured from a partial completion of the works. It is sometimes found that a small amount of work will change existing conditions so as to produce a great temporary benefit. This was illustrated at Coos Bay. When the work of building the north jetty started, there was a swash channel several hundred feet wide, and with a maximum depth of 8 ft. at low water, to be crossed by the jetty. When this swash channel was shut off, the benefit to the main channel was very marked. The depth on the bar increased to 20 ft. at low water, and remained so for some weeks. But, as was to be expected, this was only temporary; the natural forces soon rearranged matters and restored the bar depth to what it had been previously.

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THE CONSTRUCTION OF A WATER-TIGHT MASONRY DAM.*

By WALTER McCULLOH, Jun. Am. Soc. C. E.

READ APRIL 5TH, 1893.

In 1857-58 the Croton Aqueduct Department of New York City made a careful topographical survey of the Croton water-shed above Croton Dam, with a view to locating all possible sites for dams and storage reservoirs, should such reservoirs be required as the city grew and the demand for water increased. The survey was made under the direction of the late Alfred W. Craven, Chief Engineer of that department, and covered some 338 square miles of the water-shed. Fifteen sites were located as possibilities ; but of these some have since been considered impractical for various reasons.

Dams were constructed on two of these sites a few years ago by the Department of Public Works, and one more is now under construction by the same department. Four more are in course of construction by

* Discussions on this paper received before May 15th, 1893, will be published in a subsequent number.

the Aqueduct Commission, and two have recently been completed by the latter and are now in use; the latter being at "Double Reservoir I," which is familiarly known as Sodom and Bog Brook Reservoir.

This reservoir is termed double, as it is composed of two basins (Plate XXV), connected by a 10-ft. circular tunnel, 2 000 ft. long, through which the overflow of the larger passes into the smaller before any waste takes place over the spillway. The smaller, or Bog Brook basin, has an inadequate water-shed of only 3½ square miles, while its storage capacity nearly equals that of the larger. The combined storage capacity of the two basins is practically nine and one-half billion gallons.

Sodom Dam, the one which impounds the water in the larger of the two parts of Reservoir "I," is built of masonry throughout, but Bog Brook Dam is an earth embankment with a rubble core wall.

Sodom Dam is situated near the village of Brewsters, in Putnam County, New York, on the east branch of the Croton River, 18 miles above the present Croton Dam; is 54 miles from New York City, and 2 miles from the Connecticut State line. It spans a narrow gorge only 500 ft. wide at coping line, 78 ft. above the river bed, and has behind it 73.42 square miles of water-shed.

The Aqueduct Commission, in August, 1886, sent a party into the field to sink test pits and make borings at the proposed site, to locate the underlying rock and to determine its character. Upon information thus obtained a location for the dam was fixed upon which crossed the valley at about right angles to the stream (Plate XXVI), and which differed but slightly from that contemplated in previous surveys made by the Croton Aqueduct Department and the Department of Public Works.

On the site adopted, the hill east of the river (the stream flowing north at this point) showed an outcrop of hard gneiss rock which rose quite abruptly for about 30 ft. above the water and at the foot of which were large boulders, gravel and river drift. The slope back from the top of this outcrop was much flatter, rising 40 ft. in 100, and the rock was covered with but a few feet of soil. On the west side the slope of the hill starts from the river at a rate of [illegible] in 100 and gradually flattens to about 5 in 100 at the elevation of the top of the dam. The rock on this side was from 4 to 10 ft. below the surface, and was rotten and shaly for a depth of about 15 ft. The river-bed was rock, quite


SODOM DAM
E 462
DOG BROOK DAM
SODOM BASIN
DOG BROOK BASIN
E 480
E 582
E 540
MILLTOWN


BOG BROOK DAM
BOG BROOK BASIN
CAPACITY
E 582
QUARRY FOR BOG BROOK DAM
ISLAND
MILLTOWN
CROTON RIVER
LANDS ABOVE MILLTOWN COVERED IN FLOOD TIME ONLY
TO DANBURY CONN

PLATE XXV.
TRANS. AM. SOC. CIV. ENGRS.
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McCULLOH ON SODOM DAM.

DOUBLE RESERVOIR "I"

solid, with a light deposit of sand and gravel overlying it (Plate XXVII).

The hill on the east side of the river is simply a ridge parallel to, and averaging 75 ft. above it, which begins about 400 ft. behind the dam, and at the lowest point north of the dam is 9 ft. below the flow line of the reservoir. On top of the ridge an earth dam was constructed, 600 ft. long, with its top at the same elevation as the masonry dam. At the north end of the earth dam is the overflow or spillway dam, a masonry wall 8 ft. high and 500 ft. long, with the lip set at elevation 415.

The waste water, after passing over the overflow wall, flows to the old river course through a channel cut to bedrock and confined between curved retaining walls (Plate XXVI).

The principal dimensions of Sodom Dam are (Plates XXVII and XXVIII):

Length at coping	500 ft.
Length at top of foundation (elevation, 347)	240 "
Thickness at foundation	53 "
Thickness at center elevation	23 "
Thickness under coping	12 "
Height at center, greatest	98 "
Height above ground line	78 "
Elevation of top of coping (New York Datum)	425.00
Elevation of flow line	415.00
Elevation of flood line	419.00

The greatest batter is on the lower face, changing at five points between elevation 347.0 and 424.0 and varying from a rate of 9.3 in 10 to 2.7 in 10: the total batter is 37.0 ft. The rate of batter on the back face is 1 in 10 between elevation 347.0 and 387.0; from the latter point the wall is plumb to the coping.

Near the center of the structure at the back is the gatehouse, 37 x 42 ft., upon which a superstructure stands, rising 23 ft. above the dam. In this gatehouse are the sluice gates, stop-planks, etc., for controlling the discharge through two 48-in. pipes inclosed in, and passing through, the body of the dam.

After the work had been commenced, the cross-section of the dam was modified, as shown on Plate XXVIII—by the addition of 6 ft. in width

at the foundation, 3 ft. at center elevation, and 2 ft. at elevation 407.0, the top remaining unchanged. This change was thought advisable by the Aqueduct Commissioners and the engineers as an extra assurance of safety, and was made at the time when the sad details of the terrible disaster at Johnstown, Penn., were fresh in the minds of every one. The change was also a great help to construction in making it easier to hold the facing stones in their places when laid upon a sloping bed of fresh mortar.

The contract for Sodom Dam and its appurtenances was awarded to Sullivan, Rider & Dougherty, December 30th, 1887, and ground was broken by them on the 22d of February, 1888.

The first problem of importance to be solved was the care of the river during construction. Croton River usually appeared a very calm and modest stream, but in the spring time, or after a heavy rain, the water would rush through this narrow gorge at an astonishing rate, sometimes as high as 250 000 cu. ft. per minute. The floods always came suddenly, raised for about 24 hours, and then slowly receded.

Several plans of flumes were submitted by the contractors (the specifications putting upon them the responsibility of handling the water), but were not approved by the engineers, being considered inadequate to the necessity. The plan adopted was the suggestion of the engineer in charge, and consisted in throwing a timber crib-dam across the river about 80 ft. back of the dam site and from this cutting a canal, 26 ft. wide and about 15 ft. deep, into the west side hill, and entering the river again 500 ft. below the dam. Before the completion of the work this plan proved itself to be the proper mode of meeting the situation.

With the river flowing through this new channel the gatehouse and the eastern half of the dam was built to from 25 to 30 ft. above the discharge pipes, and when conditions seemed favorable in the dry season of 1889, the water was turned from the canal and through the pipes, and the remaining half of the dam was then started.

Excavations for the foundation were well under way in April, 1888, and the center 200-ft. section was ready for masonry by the end of August.

In preparing the foundation, drilling was done, both by steam and hand, and light charges of 40 and 60% dynamite used in blasting till the rock appeared firm. Then all loose seams or shakes were followed up

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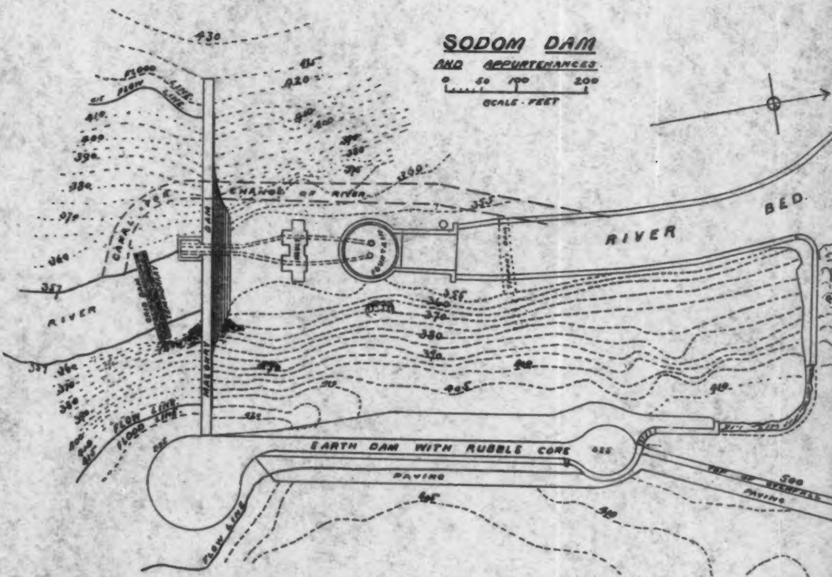
SODOM DAM
AND APPURTENANCES
0 50 100 200
SCALE - FEET
CHANNEL OF RIVER
RIVER BED
RIVER
MASONRY DAM
FOUNTAIN
FLOW LINE
FLOOR LINE
EARTH DAM WITH RUBBLE CORE
PAVING
430
420
380
370
360
357
390
400
405
410

PLATE XXVI.
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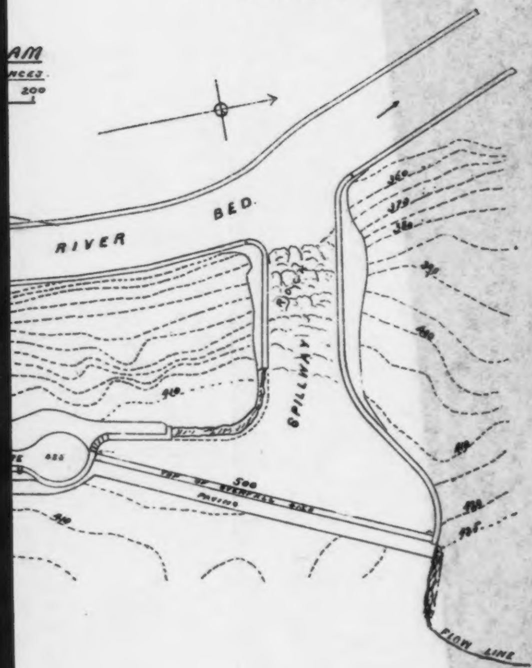
McCULLOH ON SODOM DAM.



with block holes and black powder blasting and by barring out, until a solid and practically tight bottom was secured. All excavation made in the latter manner was classified as "deep rock," for which an extra price of 50 cents per cubic yard was paid.

The foundation thus prepared was swept with wire stable brooms and washed clean with streams from hose pipes, to insure a perfect union between the rubble masonry and the rock.

When the bottom was ready for the masonry, the plan first used was to fill the pockets, or holes, with a rich Portland cement concrete, forming a series of small level beds upon which to begin the rubble. Concrete beds were discontinued after a two days' trial, because it was found that a surer and tighter bed could be formed of rubble made with small stones.

A large quantity of water made its way through the loose rock above the bottom, and in a number of places through seams in the bottom itself; but in these cases, where the rock was solid, the seams were not followed any deeper. The springs in the bottom would wash the mortar out of the concrete, and in many cases render it worthless; but in making the rubble beds the water could be led round and prevented from doing damage. These streams were nursed about from place to place till finally a small well, 2 ft. in diameter and 1 to 2 ft. deep, would be formed just around the point where the water boiled up. When the mortar about each little well had thoroughly set, the water was bailed out, the well quickly filled with dry mortar, a bed of stiff, wet mortar put on top of this, and on top of all a large rubble stone was placed, and the spring would be successfully squelched.

This process was followed over the entire bottom wherever water had to be contended with, and gave much better satisfaction than could be obtained with the concrete. After the first 6 ft. of the rubble foundation had been placed it was plain sailing, and the masonry proceeded without further difficulty.

Below elevation 357.0 the entire wall was composed of rubble masonry in 2 to 1 Portland cement mortar; but above 357.0 on the back and 364.0 on the face, it was faced with "facing stone" 30 ins. deep and backed with rubble.

Rubble stones varied from a cubic foot to a cubic yard in bulk, and in placing them the beds of mortar were made very full and the stone thoroughly shaken to a firm position. The rubble was not car-

ried on in level courses, but was broken as much horizontally as possible so as to avoid having a straight joint of mortar through the wall.

In filling the interstices the rule invariably followed was to put the mortar in first, then force into it all the spalls it would take, thus insuring perfectly filled joints, and as much stone in the work as possible. Grouting was not permitted at all.

All stones, of whatever size, were thoroughly washed before going on the wall, and were usually wet when placed in the work.

Of the entire bulk of rubble the larger part was in 1 to 2 Portland cement mortar, the remainder being in 1 to 3 Portland, and a small amount of 1 to 2 American natural cement. All the facing stone and dimension stone masonry is laid in 1 to 2 Portland cement mortar.

The largest quantity of masonry laid in one month was 3 000 cu. yds. with 12 masons and three derricks. The average progress per month was about 1 700 cu. yds.

In mixing the mortar for all classes of masonry, the practice was to mix the sand and cement dry and to wet it on the wall only as fast as it was required. The "dry mixing" was done in large boxes on the ground at the east end of the dam in batches containing three barrels of cement, and when thoroughly mixed, the dry mixture was carried in these boxes to the mortar beds on the dam, and there divided into smaller batches and wet according to the rate at which it could be used up. By following this course the best results from the cement were obtained, as the mortar would be in the work before its first set had taken place, and the necessity of "tempering up" was avoided.

The cement used was "Burham" (English) and "Giant" (American) Portland cements, and "Union" (American) Rosendale cement.

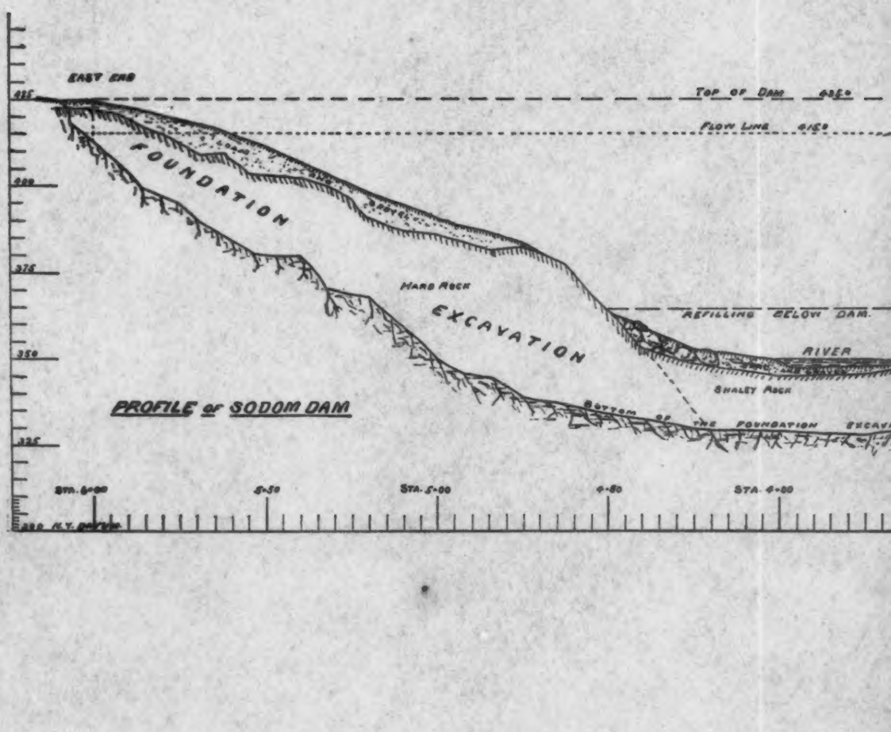
Of the total Portland cement used, only 15% was Burham.

A very careful test was made of all cements used, under the following requirements:

Tensile strength required in pounds.	One day.	One week.
Portland cement, neat..........................	110	300
American natural cement, neat..................	35	85

Fineness.

Portland 80% must pass through a sieve of 10 000 meshes per square inch.
Am. nat'l 92% " " " 2 500 " " "


EAST END
425
400
375
350
325
TOP OF DAM 425.0
FLOW LINE 415.0
LOAM AND GRAVEL
FOUNDATION
HARD ROCK
EXCAVATION
REFILLING BELOW DAM.
RIVER
SHALEY ROCK
BOTTOM OF THE FOUNDATION EXCAV
PROFILE OF SODOM DAM
STA. 6+00
5+50
STA. 5+00
4+50
STA. 4+00

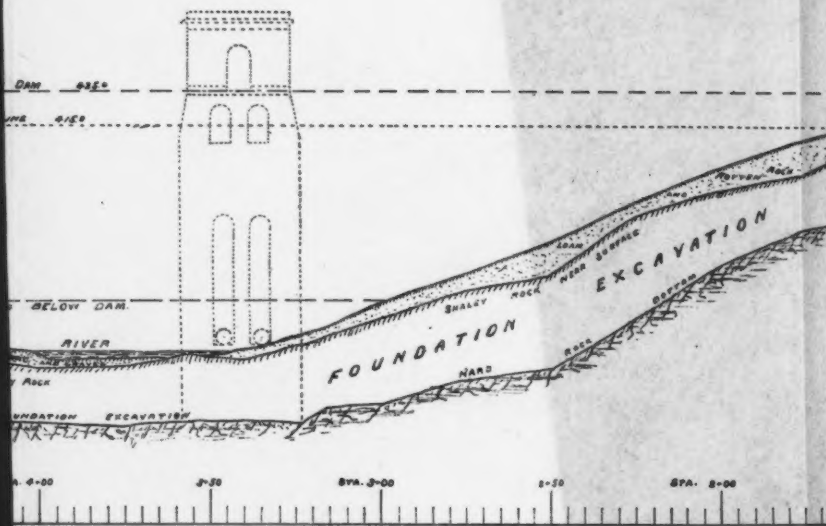

BELOW DAM.
RIVER
FOUNDATION EXCAVATION
SHALEY ROCK NEAR SURFACE
HARD ROCK BOTTOM
STA. 3+00
STA. 2+00

PLATE XXVII.
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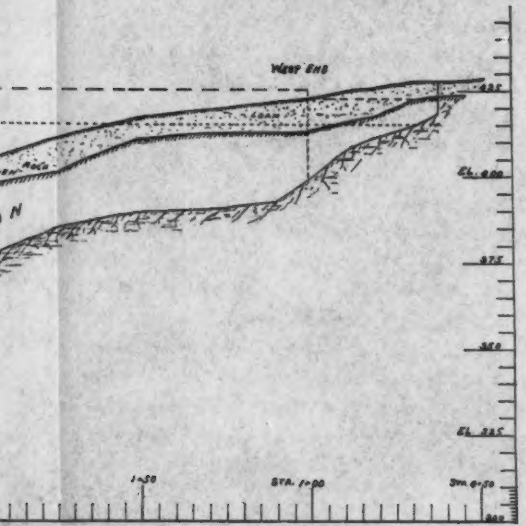
McCULLOH ON SODOM DAM.



Following are some of the results obtained from these tests :

AVERAGE TENSILE STRENGTH IN POUNDS.

BRADN.	Fineness. Average.	TIME SET IN WATER.						
		1 Day.	1 Week.	1 Month	1 Year.	2 Years.	3 Years.	4 Years.
Portland.	10 000 mesh							
Burham, neat........	80%	167	429	615	798	700	764	782
" 1 to 2 mortar	....	....	141	258	468	532	632	658
" 1 to 3 mortar	....	....	169	224	404	520	552	....
Giant, neat...........	82%	140	348	422	682	694	736	771
" 1 to 2..........	....	....	166	280	490	564	680	674
" 1 to 3..........	....	....	140	234	420	512	572	....
Natural.	2 500 mesh							
Union, neat..........	96%	160	240	228	510	542	650	654
" 1 to 2..........	....	....	34	94	394	430	514	522

An excellent quality of coarse, sharp sand was secured from pits on reservoir lands about 1 mile from the dam; each load had to pass inspection, and all containing any loam were condemned and rejected.

The quarries from which the rubble stone was obtained were about a mile and a quarter from the dam. The stone was transported on double team trucks carrying from 1 to 1½ cu. yds. at a load, and making from six to eight trips a day. The rock was a hard and tight-grained gneiss of irregular cleavage.

The facing stones were quarried and cut at a quarry opened especially for the Sodom work, at Towner's, New York, 7 miles away; were brought on cars over the New York and New England Railroad and unloaded at the dam, from which a switch was laid to and connected with the railroad.

These stones, a light bluish gray limestone, were cut rectangular, with "rock face" on exposed face, stretchers being from 3 to 6 ft. in length, and 30 ins. deep, and headers 4 ft. deep. They were laid in regular courses gradually decreasing in rise from the bottom up. The face of the stone is square with the bed, and set with bed normal to the batter.

At first considerable trouble was experienced in holding the stone up to line when set on the inclined bed, but this difficulty was overcome by building the rubble backing up first to about the height of the course which, when set, could be braced against with wooden blocks and wedges, and the stone held perfectly in place. When the stone had been set for 24 hours or more the blocking was removed and the space immediately filled with rubble backing.

All dimension stone came by rail from quarries on the Brandywine River, at Wilmington, Delaware, and was an excellent quality of dark bluish granite of a very hard, tight grain.

The plant used by the contractors in building the dam was, with but two exceptions, the "cable" and the "traveler," without novel or especially interesting features.

Three stiff-leg boom derricks with double-drum steam hoisters, and two stiff-leg derricks with double-drum horse powers, were used, which were shifted from place to place as required.

The "cable," which the writer believes was here used for the first time as part of a construction plant, consisted of a 2-in. steel wire cable weighing 7 lbs. per foot, stretched over two towers, one erected at each end of the dam 667 ft. apart and anchored into the bedrock behind the towers. Upon this cable a trolley or car ran which was entirely controlled by a double-drum reversible engine situated back of the west tower.

The cable was swung over the length of the dam, parallel to the center line, and 10 ft. from the back face, and at such an elevation that a car at the center of span loaded to 10 tons would sag the cable to 25 ft., and still clear the coping by 5 ft. when the work should reach that point.

The engine was so constructed that it controlled both the movement of the trolley from tower to tower and the raising or lowering of the load. The load could be held at any desired distance below the trolley, and run forward or back, or the trolley could be kept stationary while raising or lowering the load.

With this appliance nearly the whole of the excavated rock was removed, and all material for the masonry was delivered upon the wall. In raising the cable it was drawn up till the sag at the center was about 20 ft. below the supports at the towers. A load would add from 3 to 5 ft. to the sag.

The prime cost of the Cable plant complete and erected was $3 750.

In July, 1888, the first cable was raised, from which time it was in constant use till October 29th, 1889, when, without warning, it parted at a point 50 ft. from the east tower and fell upon the wall. At the time of the break the trolley was running out from the west end with a load of only 6 tons, and was one-third of the distance across. No satisfactory conclusion was ever reached as to the cause of the failure.

SODOM DAM SECT

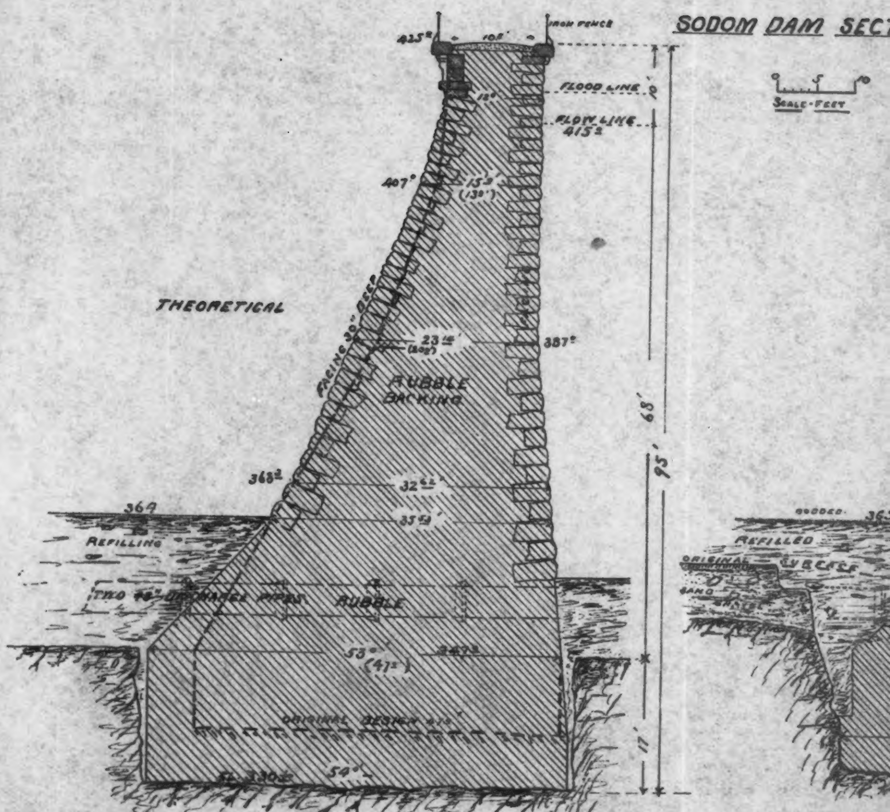


PLATE XXVIII.
TRANS. AM. SOC. CIV. ENGRS.
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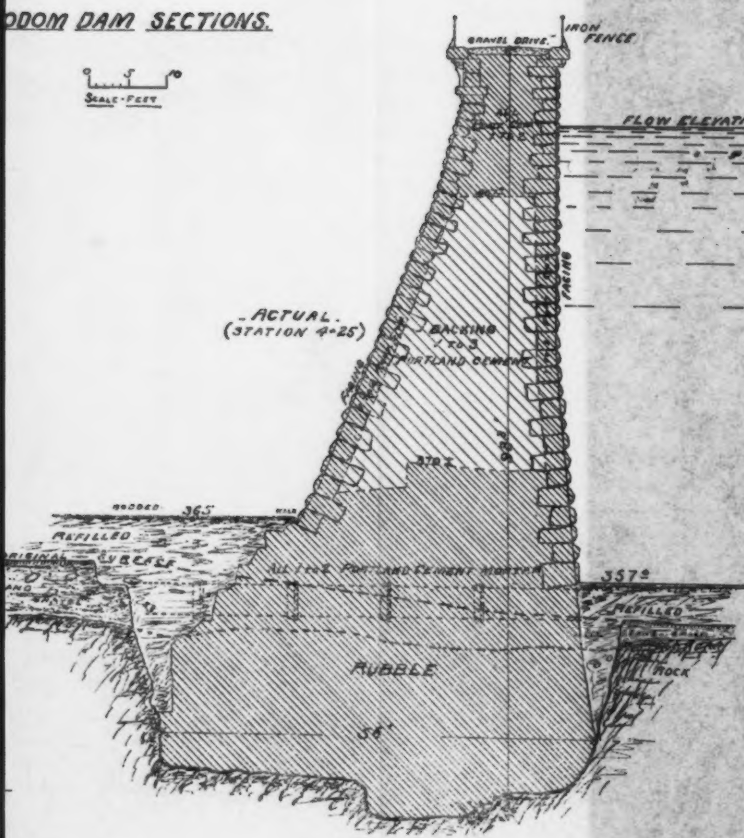
McCULLOH ON SODOM DAM.



ENGRS.
85.
M DAM.
N ELEVATION
ED
OCK

In the writer's opinion it was due to unequal wear at that point, for it parted directly over the place where stone and cement boxes were loaded and taken up by the cable. A new cable was immediately secured, and at the same time the towers were raised about 10 ft., so that it would not be necessary to draw the cable so tight, but allow a deeper sag.

No further trouble was experienced, and this second cable was kept constantly busy till the completion of the dam. When taken down in the middle of August, 1892, the cable was found to be in an excellent condition except for a reasonable amount of wear showing on the outside wires; but no broken wires were discovered.

When the wall had reached elevation 395.0, the derricks standing upon the ground were replaced by the "traveler," a traveling derrick mounted upon a 30-ft. trestle and running upon a track of 36-ft. gauge. A 55-ft. boom derrick was erected at the center of the front of the traveling platform and secured by two stiff legs to the back corners of the same, and was operated by a double-drum steam hoisting engine. With this traveler the dam was completed between the points that could be reached by derricks placed upon the side hills.

From start to finish the work seemed destined to delays of all kinds. The celebrated blizzard of March, 1888, was the first serious setback received. Then followed two unusually wet summers causing a great deal of broken time and consequent loss.

In November, 1889, the most serious of the floods came upon us, and a shutdown for the season was the consequence. All the month of November had been rainy, but on the 28th the climax was reached when in 18 hours the rainfall was 3.8 ins., bringing the total fall for the month up to 8.7 ins. Eight hours after the rain had ceased, the water behind the dam had raised 10 ft., and in 12 hours had raised 15 ft. and was pouring over the top of the wall in a perfect torrent, notwithstanding the fact that both 48-in. pipes were open and discharging at their full capacity all the while.

Provision had been made for such an emergency by always keeping that portion of the dam directly over the new river channel from 4 to 5 ft. lower than the remainder.

A most serious loss was met with in January, 1889, when John Sullivan, the head of the contracting firm, was removed by death after

but a few days' illness. To him had been left entirely the organization of the work and the planning for its future conduct. After Mr. Sullivan's death, his interest in the contract was cared for by his executor, Clinton Stephens; P. J. Dougherty, another member of the firm, assuming the superintendence of the work till its completion.

Many other delays, such as strikes at the granite quarry and on the railroads, failure of the railroads to deliver cement and other materials on time, the exhausting of materials, etc., occurred from time to time, so that instead of the contract being completed on December 31st, 1889, the specified time, it was not finally finished and accepted till October 31, 1892.

Only one fatal accident occurred during the whole course of construction, and that was caused by the breaking of the cable on October 29th, 1889. An Italian mortar-carrier was struck on the head by a piece of the trolley and killed. Three minor accidents occurred in which the sufferers required hospital attention.

Labor employed was for the most part foreign, at prices ranging from \$1 25 for laborers to \$3 50 for stone-masons.

The following is a partial list of the quantities of materials handled in the excavation for, and masonry in the construction of, Sodom Dam and the gate-house, and the contract-price paid for the same.

Quantity. Cubic Yards.		Price.
5 986.	Earth excavation	\$0 35
16 260.	Rock excavation	1 50
3 600.	Deep rock excavation	2 00
300.	Rubble masonry, 1 to 2 Am. cement	3 75
23 280.	" " 1 to 2 Portland cement.	4 50
6 260.	" " 1 to 3 " "	4 25
530.	Brick " 1 to 2 " "	10 25
776.	Granite dimension stone masonry, 1 to 2 Portland cement	35 73
4 287.	Facing stone masonry, 1 to 2 Portland cement	10 75

The total bulk of masonry of all classes in the dam is 35 887 cu. yds.

The contract prices for the largest and most important items on the whole work were extremely low, considering the situation and the requirements, and this made it hard upon both the contractors and the engineers to secure a first-class quality of work under such unfa-

PLATE XXIX.
TRANS. AM. SOC. CIV. ENGRS.
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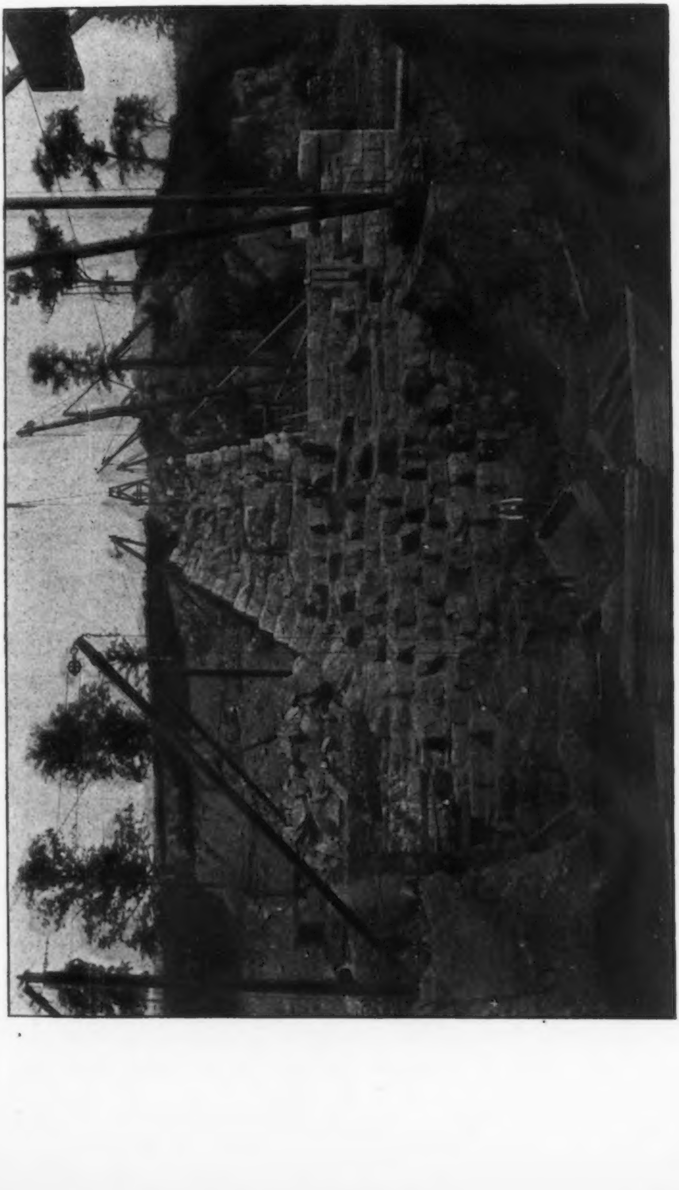
McCULLOH ON THE CONSTRUCTION OF A WATER-
TIGHT MASONRY DAM.



vorable circumstances, but it must be said to their credit that the contractors faithfully lived up to their contract, even if at a loss.

The dam now stands in testimony of the accomplishment of the desired result in every respect.

It is impossible to give exact figures upon the cost to the contractor of the different classes of work, owing to accounts not having been kept with this end in view.

The following are some figures on the costs, estimated from such data as could be obtained:

Cement in shed at dam, per barrel:	
"Burham," Portland	$2 51½
"Giant," "	2 31½
"Union," Natural	1 00½
Rubble stone from quarry on work, including 5 cents royalty, per cubic yard	1 97
Rubble stone and spalls from excavation waste banks	67
Rubble stone, average from all sources	1 26
Facing stone on work, including 15 cents royalty, per cubic yard	9 75
Dimension stone on work, including dressing, per cubic yard	30 08
Rubble masonry, 1 to 2 Portland Cement, per cubic yard	4 45
Facing stone masonry, per cubic yard	10 97

The dam was far enough advanced by the winter of 1890–91 to admit of storing water behind it to elevation 390.0, and by the following winter to elevation 415.0. The extra storage supply was absolutely necessary to meet the demand in the summer, since the new aqueduct had been brought into use by this time and the daily allowance to the city had been greatly increased. This early use of the dam caused some inconvenience to construction, and was also a premature test upon the green masonry, but no evil results came from it.

Sodom Dam was finally completed on October 29th, 1892, and formally accepted by the Aqueduct Commissioners on December 28th, 1892. The final estimate for dam and appurtenances amounted to $436 499.05.

When the bids upon this work were received on December 7th, 1887, Sullivan, Rider & Dougherty's bid was $366 990, they being the lowest. The highest bidder was Miles Tierney, at $584 315, and the Engineer's estimate was $540 030; all figured upon the same basis.

The difference between the amount bid and the final estimate is due to modifications made from time to time in the original plans.

As to the water-tightness of Sodom Dam, it is perfect. When the reservoir is filled (with 68 ft. of water behind the wall) many careful examinations have failed to disclose any leaks whatever, either through the wall or under it, or through the rock around the ends in the side hill. "Sweating" at the joints in the facing stone appears at several points only, but not in sufficient quantity to produce a trickle. What moisture there is will wholly disappear on a dry, clear day; but if the day be humid, dampness is visible upon the face of the stone as well as at the joints.

To the question, "Upon what did the successful construction of Sodom Dam as a water-tight structure depend?" the writer's reply is: 1st, upon the excellent quality of the material used and the methods adopted in using them, viz.: the securing and preparing a solid, tight foundation, the care to have every stone perfectly cleaned with water, the prompt use of mortar after wetting, the perfect filling of every joint with mortar, and the placing of stones so as to always break joints both horizontally and vertically; 2d, upon the careful study and close attention, given by the engineers in direct charge, to every detail to see that the above methods were faithfully carried into effect; and 3d, upon the desire and endeavor on the part of the contractors to do good work and the existence of a proper relationship between them and the engineers, which the writer thinks is a most important factor in securing thoroughly satisfactory work.

From start to finish the engineers had ever before their minds the fact that they were building to resist water, one of the most subtle and persistent enemies that our profession has to cope with, and they permitted no defects in construction, however trivial they might appear at the time, to pass unremedied.

The engineers to whom was entrusted the direction of work by the Chief Engineer, A. Fteley, were George B. Burbank, Division Engineer, and the writer as Assistant Engineer in charge, from the commencement until June 17th, 1891, when, upon Mr. Burbank's resignation, the writer became Division Engineer, and assumed charge, with Frank N. Speyer as his assistant.

In conclusion, the writer feels safe in saying that for water-tightness Sodom Dam rivals all masonry dams previously constructed in this country, and stands in the front rank with, if not ahead of, those built abroad.

PLATE XXX.
TRANS. AM. SOC. CIV. ENGRS.
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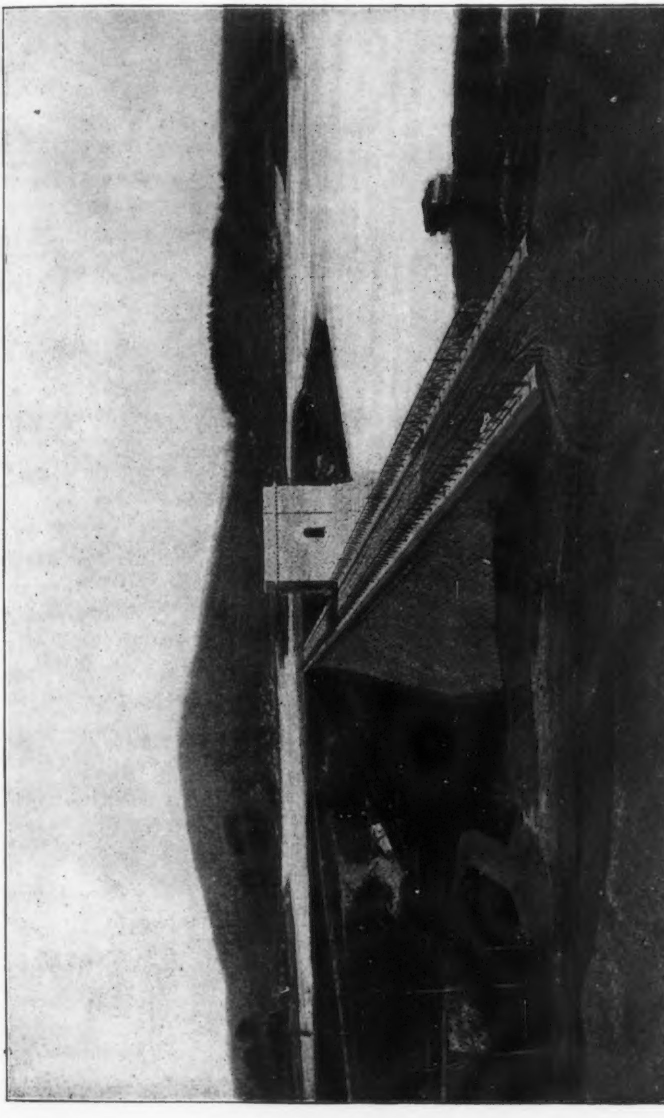
McCULLOH ON THE CONSTRUCTION OF A WATER-TIGHT MASONRY DAM.



In answer to questions put by members of the Society after the presentation of the paper, the following additional information was given by Mr. McCulloh:

Cements.—The American natural cement used was the "Union" brand from Egypt, Pennsylvania, and was delivered in heavy duck bags containing 100 lbs. each, three bags constituting a barrel. The "Giant" Portland cement came from the same mill as the "Union," in bags of 100 lbs. each, four bags to the barrel.

The purchaser of the cement was charged with the price of the bags, which, if returned, he was given credit for upon his next order.

No greater loss or damage to the cement was sustained in using bags than had casks been used.

Testing samples were taken at random from about 10% of the bags in each lot received, and, if any question arose about the test, a second and independent set of samples was taken, and a new test made. In the average tensile strains given in the table of tests, some figures are the result of over 1 000 breaks. The lowest number of breaks is probably about 15 or 20, but the average is over 100.

Masonry in Freezing Weather.—A small portion of the dam was built in freezing weather, in December and early January of two winters. This was considered necessary as it was desired to store water behind the dam to a certain elevation, and to do it the back half for a height of 4 or 5 ft., and 200 ft. long, was built in this way. Hot brine (5 lbs. salt to 1 bbl. of water) and heated sand were used in making the mortar, and the rubble stones were also treated. Work was only allowed to proceed when the temperature was above 20° Fahr. To protect the fresh mortar at night, salt would be scattered over it, and if the conditions indicated a severe night in prospect, a layer of sand was spread over it also. No straw was used to protect masonry.

In the spring the masonry laid in winter showed only slight damage on the surface. A thin crust or scale $\frac{1}{16}$ to $\frac{1}{8}$ in. deep could be scraped off and would disintegrate. Under this scale the mortar was in good condition and set hard.

Each spring the old mortar was gone over with sharp picks, chisel edged, to remove the scale and secure a clean, fresh surface for the new mortar to fasten to.

It was not observed that the use of hot brine and sand caused the mortar to set more rapidly than usual.

Freezing Tests of Cements.—Certain tests were made at the laboratory, both with and without using brine, to observe the effects of freezing; but they were not complete enough to draw any positive conclusions from them. The results obtained were slightly in favor of the use of salt. Mortar frozen immediately after mixing would crumble, but, upon thawing, the mass would then set very satisfactorily, the freezing simply suspending the setting. Briquettes broken after a week's exposure to frost showed slight falling off of strength, but the difference was no greater than was often observed between two sets of samples under ordinary tests.

Portland and native cements acted practically the same under the same conditions of freezing.

Cable.—The main cable was 2 ins. in diameter, made of seven strands of 19 wires each, or 133 wires in all. The total length between anchors was 990 ft. The anchors, back of the towers, were oak "deadmen," 10 ft. long, 2 ft. diameter, in trenches cut 6 ft. into solid rock. Near one anchor was a turn buckle used to take up the "stretch" due to constant use and variations in temperature—the total stretch was about 3 ft. No twisting motion in the cable was observed as a load was run out upon it. The greatest indication of wear was in the cast-iron trolley wheels, which would be cut in regular spiral grooves corresponding to the strands of the cable.

Cable Failure.—The break that occurred in the first cable took place between towers 50 ft. from the one farthest from the power-house, and at the time the load was slowly moving from the power end toward the center. It parted directly over the point where the rubble stones were lifted from the trucks by the trolley. When observed, after the break, both ends were found frayed for about 10 ft., and each wire showed a contraction at the point of parting, as is the case in testing samples.

Both cables were made by Cooper, Hewitt & Co., and were of the same dimensions. The original plant was furnished by the Lidgerwood Manufacturing Co.

Preserving Batter Lines.—As each course of facing stone was completed, the true batter points for that course were established upon it by the engineers every 20 ft., using the instruments. These points were cut into the stone, and the foreman was required to work from them for each succeeding course. At each change of batter, short profiles were set by the engineers 50 ft. apart, to insure the correct setting of the first course at the new rate of batter.